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SOIL CHANGES
RESULTING FROM NITROGENOUS FERTILIZATION

A LYSIMETER STUDY

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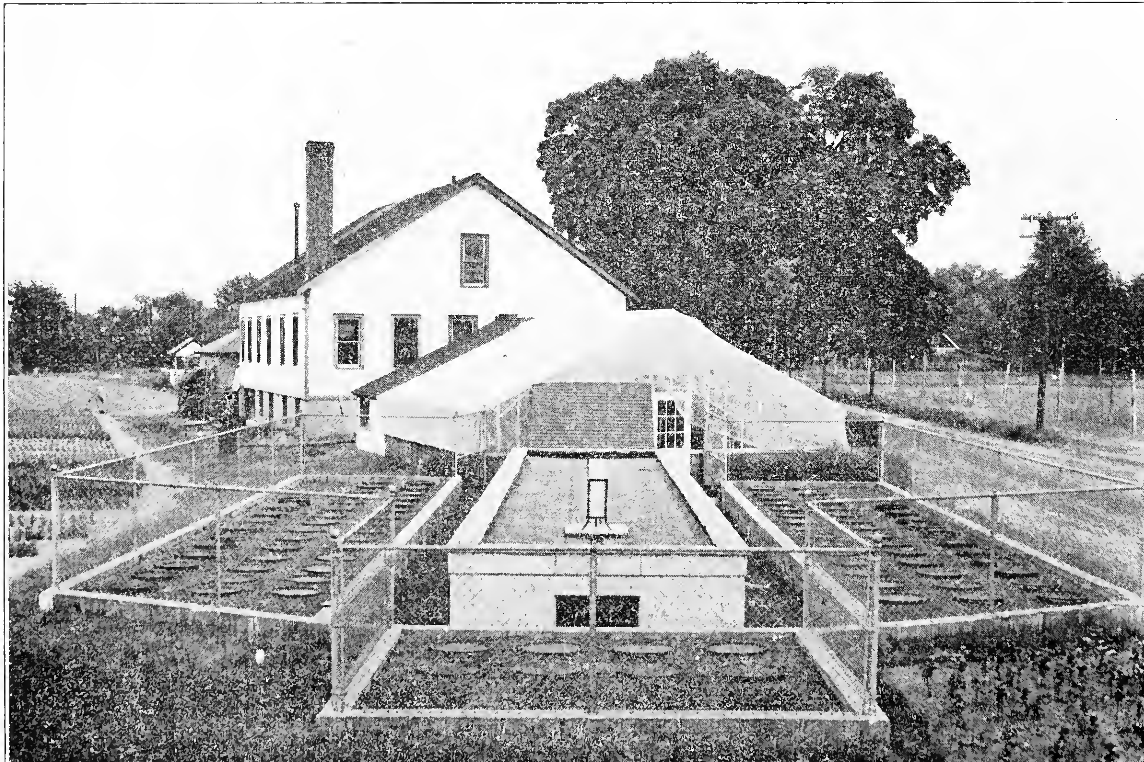

General View of Windsor Lysimeter, 1936.

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M. F. Morgan*

Under the systems of intensive fertilization now widely used for tobacco, potatoes and vegetable crops in Connecticut, annual application of nitrogen ranges upward to 200 pounds per acre. In many cases the amount applied exceeds the removal by the crop. Various sources of nitrogen are commonly used, differing widely in chemical characteristics and rate of availability in the soil.

The present report embraces a study of a few of the more common carriers of nitrogen with respect to chemical changes induced in soils by their continued use at a liberal rate. The data are based on a set of lysimeter tanks installed at the Windsor Substation in 1929.

Lysimeter series "A" involves a comparison between nitrate of soda, sulfate of ammonia, urea and cottonseed meal. Each was applied at an annual rate of 200 lbs. of nitrogen per acre, to four soils of differing physical and chemical characteristics. In this series, surface soils alone were studied under uncropped conditions, during the five years ending in 1934.

Lysimeter series "B" is a study of the same materials investigated in series "A", as well as of 12 other sources of nitrogen. Nitrogen was supplied at the rate of 200 lbs. per acre per year in each case. A typical tobacco soil, with a moderate depth of subsoil, was studied in tanks of sufficient depth to permit annual cropping to tobacco. This series of lysimeters, started in 1929, is being continued at present. Therefore the data here presented are incomplete.

Drainage waters from the above lysimeters have been fully analyzed over a period of five years. The soils in the tanks of series "A" were removed in April, 1934, and changes with respect to exchangeable bases and related factors were determined by comparisons with the original soils when placed in the tanks at the beginning of the experiment.

This combination of precise information as to fertilizer application, drainage losses and soil measurements affords an unprecedented opportunity to evaluate the influence of the various nitrogenous materials upon the soil.

REVIEW OF THE LITERATURE

Soil changes induced by nitrogenous fertilization have been observed by many investigators. An exhaustive review of the literature would make up a cumbersome volume. However, the following pages suffice to trace the development of present points of view.

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*Previously presented in slightly different form in partial fulfillment of the requirements for the degree of doctor of philosophy, Ohio State University, June, 1935.

The classical studies of Way (50) (1850-52) first disclosed the ability of soils to absorb ammonia from solutions of its salts, displacing an equivalent amount of calcium. These observations were fundamental to the development of our present concepts of the interaction of bases in the soil now designated as "base exchange". The effect of nitrogenous fertilizers upon the soil is closely related to this phenomenon.

Meyer (25) (1881) pointed out the effect of cropping in relation to the action of fertilizers upon the soil. He introduced the concepts of physiological acidity and alkalinity, depending upon whether the crop took up an excess of basic or acidic constituents, respectively, from the fertilizer salt in question. Thus ammonium sulfate was designated as physiologically acid, as a result of ammonia absorption by plant growth, while sodium nitrate was considered to be physiologically alkaline, as a result of intake of nitrate and rejection of sodium in the process. Although his publication was overlooked for many years, it has greatly affected thought along these lines during the past two decades.

Lawes, Gilbert and Warington (22) (1882) in discussing the composition of drainage waters from the plots on Broadbalk field, comment as follows:

> "When ammonium-salts are applied to the land, the quantity of matter removed in the drainage-water is much increased; thus in the water from Plot 10, receiving 400 lbs. of ammonium-salts alone, the dissolved matter reaches 441.8 per million. When ammonium-salts are added to the mixed mineral manure, the solid contents of the drainage-waters rises in proportion to the quantity of these salts applied. Thus in the drainage-waters from Plots 6, 7, and 8, to which 200, 400, and 600 lbs. of ammonium-salts are applied, the mean proportion of total solid matter is respectively 450.3, 542.4, and 615.1 per million.
>
> "The solid matter removed from the soil by the agency of the ammonium-salts consists chiefly of sulphate, chloride, and nitrate of calcium. Probably the whole of the sulphuric acid and chlorine contained in the ammonium-salts unites with lime and magnesia in the soil; the resulting salts being soluble, they will be removed, to a greater or less extent, in the drainage water as soon as a sufficient rainfall occurs. The 400 lbs. of ammonium-salts would be able to remove annually from the soil in this way about 172 lbs. of lime. The actual loss of lime would, however, be somewhat less, as a part of the sulphuric acid and chlorine of the ammonium-salts would be retained by the crop. Loss of lime would also occur as nitrate of calcium. Ammonia is speedily oxidised to nitric acid in the soil: this acid combines with lime and magnesia in the soil, and nitrates appear in the drainage-water. Supposing that the whole of the ammonia were converted into nitric acid, and that the resulting nitrates were entirely lost by drainage, the soil would suffer a further loss of about 172 lbs. of lime for 400 lbs. of ammonium-salts applied. On a cropped soil, of course, the loss on this score would be greatly diminished, as the crop would assimilate a large part of the nitrates formed. The action of ammonium-salts in impover-

ishing a soil of lime and magnesia should always be borne in mind when their application to soils poor in lime is in question."

The above statement clearly pictures the relation of sulfate of ammonia fertilization to the removal of bases in the drainage water.

However, the net effect of this increased base outgo in producing symptoms of soil acidity was not noted until 1893, when Wheeler and Towar (51), at the Rhode Island Station, obtained especially beneficial results from liming part of a plot treated with sulfate of ammonia. They considered the acidity as due primarily to the setting free of sulfuric acid and ascribed the beneficial effects of lime to enhanced nitrification. Similar symptoms of soil acidity resulted from repeated treatments with sulfate of ammonia at Woburn and were reported in 1899 by Voelker (49).

Hall (17) (1909) showed that ammonium sulfate was effective inproducing decomposition of calcium carbonate in the highly calcareous soil at Rothamsted, "117 lbs. of carbonate of lime being removed for each 200 lbs. of ammonium salt applied." In discussing the development of acidity on sulfate of ammonia plots on the Park Grass field at Rothamsted, Hall ascribed it to the action of micro-fungi, which assimilated the ammonia in their own nutrition, thus setting free the acid. Nitrification was not considered to be a factor, since it was believed that this process was wholly inhibited by a very slightly acid medium.

Eckart (15) (1906) conducted lysimeter experiments with nitrogenous fertilizers in perforated tubs, using artificial watering every two weeks to produce leaching. Maximum calcium in the drainage water was produced by sulfate of ammonia, although less nitrate nitrogen was recovered than in the case of nitrate of soda. Peck (34) (1917), conducting similar experiments on a soil containing a large excess of lime, found smaller amounts of nitrate leached from nitrate of soda than from sulfate of ammonia, although more calcium appeared in the drainage from the latter treatment.

Collison and Walker (10) (1916), in lysimeter tanks planted to young orange trees, found greater leaching of nitrates from nitrate of soda than from sulfate of ammonia, while the reverse was true of the outgo of calcium and potassium. "Tanks 1 and 2, receiving sulfate of ammonia, a material which increases soil acidity, lost on the average 569 grams of lime, while tank 3, receiving nitrate of soda which leaves a basic residue in the soil thus tending to decrease the acidity, lost 242 grams of lime."

It is also to be noted that Collison (9) found no bicarbonates in the leachings from sulfate of ammonia tanks in 1916-1917, and a notably greater concentration of both potash and magnesia than in the drainage water from the nitrate of soda treatment. This was the last period of reliable data in this experiment.

Ruprecht and Morse (42) (1915), in an effort to explain the acidity resulting on sulfate of ammonia plots, found increased calcium, sulfur and total solids in the drainage from tile under this treatment. They stated that the soil absorbs ammonia, and that either double decomposition or physical absorption operates to cause combination of the sulfate radical with calcium from calcium carbonate, when present, or with calcium from its salts. They also noted increase in soluble aluminum and iron as a result of sulfate of ammonia treatment, and in a subsequent publication, ascribe the cause of the injurious effect of the soil under

this treatment to the formation of sulfates of aluminum, iron and manganese. Data given by Morse (30) in 1921 show the presence of 235 lbs. per acre of manganese sulfate in this soil, an amount almost equivalent to the sulfate of ammonia application for the season.

Frear (16) (1915) stated as follows in regard to sulfate of ammonia: "Its continuous use inevitably tends to produce pronounced acidity in the soil. The reasons for this are not fully understood, although it is clear that it yields two acids,nitric and sulfuric, but no base, when nitrified."

Ames and Schollenberger (4) (1916) pointed out that when a neutral salt is added to the soil, the base is rapidly removed from solution and held by the soil, leaving the acid to combine with any constituent which may be soluble. Thus the soil is no poorer in bases than before. "In the case of ammonium sulfate, however, the absorbed base is capable of becoming acid through the process of nitrification, and a further amount of basic material will be removed from the soil," However, they fail to indicate the action of leaching or crop removal in this process.

Allison and Cook (3) (1917) found the average increase in acidity produced by ammonium sulfate in greenhouse pots to be equivalent to 80 lbs. of calcium oxide per 100 lbs. of ammonium sulfate used, on the basis of lime requirements by the Veitch method. Increases in acidity were not consistently different on cropped and fallow soils.

Howard (20) (1919) reported an increase in exchange acidity in soils treated with sulfate of ammonia and attributed it to the hydrolysis of aluminum salts. Thus there is a change in ratio of acids to bases, the position normally occupied by the stronger bases being taken by weaker bases, such as aluminum and iron.

Morse (29) (1918) made colorimetric pH tests on water extracts of the old fertility plots at Amherst, finding as follows: No nitrogen—5.4 pH; sulfate of ammonia—4.9 pH; nitrate of soda—6.0 pH.

Burgess (8) (1922) was the first to make a systematic application of hydrogen-ion concentration measurements to a study of the effects of nitrogenous fertilizers upon the soil itself. The plot receiving a total of 6,514 lbs. of sulfate of ammonia during the period 1893-1921 was found to be at 4.62 pH, despite four applications of calcium oxide at the rate of 500 lbs. per acre during the last few years prior to measurement. On the other hand, an equal amount of nitrogen as nitrate of soda, throughout the same period, produced a final reaction of 5.24 pH, with no lime at any time. These differences were also confirmed by "lime requirement" determinations.

> "In this connection it is interesting to note that between May 24 (which was soon after the fertilizer was added) and July 28, there was a decided increase in hydrogen-ion concentration. An explanation may be that, within this acid soil, after the solution and ionization of the nitrate of soda, the cation combines at once to form insoluble, complex silicates, leaving the anion more or less free in the soil solution until subsequently absorbed by the growing plants as their source of nitrogen."

Crowther (11, 12) (1925) studied the reactions of the Rothamsted "Park Grass" plots, and the Woburn barley plots. The acid effects of ammonium salts were conspicuous in both these series, while sodium ni-

trate gave slight decreases in acidity. A 50 per cent increase in rate of application of ammonium salts on the "Park Grass" plots lowered the pH from 4.0 to 3.8, indicating the latter figure as approaching the limit of acidity capable of being developed on this soil. However, the heavier application produced a marked increase in acidity of the subsoil.

A noticeable degree of flocculation of the subsoil was observed on plots treated with ammonium salts. This was not apparent in the surface soil, possibly as a result of protective action by the humus colloids. The condition in the subsoil was ascribed to the accumulation of calcium and aluminum that leached from above.

The Woburn barley plots, receiving 7600 lbs. of ammonium sulfate in 46 years, which were limed with two tons of calcium oxide (equivalent to 7140 lbs. $CaCO_3$) were still somewhat more acid than plots treated similarly without sulfate of ammonia or lime. At the same time, three tons of lime (equivalent to 10,710 lbs. of $CaCO_3$) were more than sufficient to overcome the acidity due to sulfate of ammonia.

The increased acidity due to sulfate of ammonia was noted at all depths to 36 inches, although the changes in pH decreased with depth.

Hartwell and Damon (19) (1927), in comparing sulfate of ammonia and nitrate of soda plots continued since 1893, found that an average annual application of 422 lbs. of CaO per acre, with sulfate of ammonia at the rate of 49 lbs. of nitrogen per acre per year, produced the same final reaction (6.3 pH) as an equal amount of nitrogen as nitrate of soda, with 275 lbs. of CaO per year. In other words, to neutralize the effects of applying 100 lbs. of sulfate of ammonia required 120 lbs. of limestone, more than was required by the same amount of nitrogen as nitrate of soda. These plots had been cropped to a wide variety of species.

Pierre (36) (1927) showed that the time required for developing a given degree of acidity from successive applications of ammonium sulfate is dependent upon the buffer capacity of the soil, and developed a method for comparing different soils in this respect. This apparently explained the fact that light sandy soils have suffered more quickly from the acid effects of sulfate of ammonia than heavier textured soils.

Kappen (21) (1927) emphasized the physiological aspects of the effects of fertilizers upon soil reaction. His logic is founded upon the earlier observations of Meyer (25), previously reviewed. Kappen recognized that in case of ammonium sulfate much of the nitrogen is converted into nitrates before assimilation by the plant.

> "Sulfate of ammonia is, therefore, a physiologically acid fertilizer in more than one respect. It has a physiologically acid effect owing to the fact that it can be transformed by cultivated plants or generally all higher plants, and further owing to the transformation effected therein under the influence of the microorganisms of the soil. It is, however, impossible to say definitely to what extent each of these two factors have to be considered. From the result of our recent experiments we are able to say that the influence of the microorganisms is not to be underestimated."

Page (33) (1927) considered nitrification to be the cause of the acidity developed by ammonium sulfate. He concluded that it makes no dif-

ference in the acidity formed whether or not the calcium sulfate resulting from the base exchange reaction leached out or remained in the soil. He believed that the term "physiological acidity" is not strictly correct, since the action is not caused by the plant, but is strictly a chemical or biological process.

Pierre (37) (1928), in greenhouse trials with various sources of nitrogen under continuously cropped conditions, measured acidity in terms of pH and exchangeable hydrogen. The pots were not leached. Sodium nitrate decreased the hydrogen-ion concentration, while sulfate of ammonia gave a marked increase. Urea was about 50 per cent as effective as sulfate of ammonia in increasing acidity. Similar results were indicated by the exchangeable hydrogen data. The change in exchangeable hydrogen produced by the nitrogenous fertilizers was in close agreement with the theoretical amounts developed, on the basis of the following assumptions:

1. From one molecule of ammonium sulfate, two molecules of a dibasic acid are eventually formed through the reactions:

   (1) $(NH_4)_2SO_4 + CaX \longrightarrow CaSO_4 + (NH_4)_2X$

   (2) $(NH_4)_2X + O_2 \xrightarrow{\text{nitrification}} 2HNO_3 + H_2X + 2H_2O$

   (3) $2HNO_3 + CaX \longrightarrow Ca(NO_3)_2 + H_2X$

2. From 1 molecule of urea, one molecule of dibasic soil acid is formed through the reactions:

   (1) $CO(NH_2)_2 \longrightarrow 2H_2O + (NH_4)_2CO_3$

   (2) $(NH_4)_2CO_3 + CaX \longrightarrow CaCO_3 + (NH_4)_2X$

   (3) $(NH_4)_2X + O_2 \xrightarrow{\text{nitrification}} 2HNO_3 + H_2X + 2H_2O$

   (4) $CaCO_3 + 2HNO_3 \longrightarrow Ca(NO_3)_2 + H_2O + CO_2$

3. Under cropped conditions, approximately one-half of the nitrate intake by the plant is in the form of nitric acid; hence, under conditions of complete removal of nitrates by cropping, sulfate of ammonia develops only 75 per cent, and urea only 50 per cent of their theoretical acidities, while nitrate of soda produces alkalinity equivalent to one-half of its nitrogen content.

In an accompanying paper Pierre (38) gave data showing that 4 lbs. of sodium nitrate were equivalent to 1.2 lbs. of calcium carbonate in correcting the acidity of 1 pound of ammonium sulfate.

Allison (2) (1931) critically reviewed Pierre's data, with especial emphasis upon the effect of base-acid ratio in the crop. He assumed that if complete nitrification and absorption by the plant takes place without an increase in base intake by the crop, 2 pounds of calcium oxide should be required to neutralize the acidity resulting from 1 pound of nitrogen as ammonium sulfate. His computation of Pierre's data showed that 2.62 pounds were actually required, under the conditions of the latter's experiment. In other words, 0.62 pound of CaO per pound of nitrogen was required to compensate for the excess removal of bases by cropping. Allison concluded "that in the comparative sense the acidity which develops is due to sulfuric acid only, if the nitrogen is removed by a crop. Urea would produce no acidity under these conditions. Nitrification cannot appreciably affect permanent soil acidity unless the nitrate salts are removed as such from the soil by leaching or otherwise, or remain in the soil permanently as nitrates."

Morgan and Anderson (27) (1928) found the following soil reactions on plots cropped to tobacco. A single application of nitrogenous materials, at the rate of 200 lbs. of nitrogen per acre, had been used for one year:

Nitrate of soda	5.41 pH
Sulfate of ammonia	4.99 pH
Urea	5.03 pH
Cottonseed meal	5.21 pH

The acid tendency of sulfate of ammonia was apparent on every plot where it was applied in combination with other nitrogenous fertilizers, while the reverse was true of nitrate of soda.

Schollenberger and Dreibelbis (45) (1930) in an exhaustive study of the exchangeable bases of the soils on the old five-year rotation plots at Wooster, gave the first definite data on the changes in base-equilibria of soils resulting from nitrogenous fertilizers. The use of the various forms of nitrogen in light amounts (equivalent to approximately 320 lbs. in 31 years) has resulted in the distribution of exchangeable bases presented in Table A (from Schollenberger and Dreibelbis' Table 3):

Table A. Exchangeable Bases in the Soils From the Wooster "Five-Year Rotation" (In milli-equivalents per 100 gm. soil)

	(Unlimed series)									
	H	Ca	Mg	Mn	Al	K	Na	NH_4	Total	pH
$NaNO_3$ minerals	6.28	1.34	.22	.24	.10	.16	.13	.10	8.47	4.82
$(NH_4)_2SO_4$ minerals	6.91	0.77	.14	.35	.30	.21	.05	.19	8.62	4.47
Dried blood minerals	6.88	1.36	.20	.27	.17	.18	.10	.09	9.08	4.73
Minerals only	5.66	1.61	.25	.27	.24	.24	.01	.12	8.16	4.81
Av. check plots	6.11	1.23	.24	.27	.28	.10	.04	.09	7.60	4.76

Sulfate of ammonia is thus seen to result in the highest exchangeable hydrogen, aluminum, manganese and ammonia, and the lowest calcium and magnesium. Dried blood has produced some acidity, as measured by exchangeable hydrogen. Nitrate of soda at this low rate of application has had little effect, other than decreasing "exchangeable" manganese and aluminum, with a comparatively slight increase in sodium.

On the limed plots, the effects of these amounts of nitrogen were so masked by the predominance of calcium in the base exchange complex that no significant differences were to be noted.

Swanback and Morgan (46) (1930) showed rapidly increasing acidity following 200 lbs. per acre application of nitrogen in any form, on a fallowed soil, corresponding with increase in nitrate content of the soil. It was significant that urea, producing high concentration of nitrates more quickly than did sulfate of ammonia, gave as high or higher acidity during the same period, and remained very high until the fall months. The lower acidity attained by cottonseed meal during the summer season apparently is associated with its lower nitrate production. It is to be noted that nitrate of soda at this rate of application produced more

acidity (in aqueous suspension) than when no nitrogen was applied. This is probably due to increased hydrogen-ion concentration as a result of exchange reactions. Measurements of the pH of acid soils in the presence of large concentrations of neutral salts are normally lower than in pure aqueous suspension. (The above results are on the same soils and treatments used in the present study, for the first season.)

Barnette and Hester (5) (1930) gave data on base exchange determination of Norfolk sand treated with varying amounts of sulfate of ammonia, at bi-weekly intervals, under grass sod conditions. The decrease in exchangeable bases was proportional to the amount applied, up to 5000 lbs. per acre per year. Using the data for the 3000 lbs. per year application, at the end of 17 months, or after 4250 lbs. of sulfate of ammonia had been added, decreases on exchangeable bases were as follows, for the various layers, in milli-equivalents per 100 gms. of soil:

Depths	Ca	Mg	K	Na	Total
0–9″	1.536	.400	.064	.033	2.033
9–21″	.571	.150	.000	.064	.785
21–33″	.264	.000	.085	.097	.446

If the above decreases in total exchangeable bases are computed on the basis of 300,000 lbs. per acre-inch, the net effect of 4250 lbs. of sulfate of ammonia is equivalent to 4843 lbs. of $CaCO_3$.

Ravikovitch (41) (1930) showed a marked decrease in exchangeable calcium and an increase in calcium absorption from $CaCO_3$ paste, as a result of 20 years' fertilization with sulfate of ammonia, at the rate of 60 lbs. of nitrogen per acre per year. Sodium nitrate at corresponding rates has slightly increased exchangeable calcium and decreased the degree of unsaturation with respect to bases.

Morgan, Street and Jacobson (28) (1931) gave preliminary data based on the first year's results of the present study. Sulfate of ammonia materially increased the leachings of calcium, magnesium and potassium. Urea produced greater calcium losses than cottonseed meal, as would be expected on the basis of the more complete nitrification of the former material. The nitrate outgo under nitrate of soda treatment was largely in the form of sodium nitrate. The appearance of large amounts of manganese and aluminum in the leachates from the two most acid soils treated with sulfate of ammonia is in harmony with the ideas of Ruprecht and Morse, previously cited. There was a close correlation between the reactions of the leachates and the amounts of manganese, aluminum, and bicarbonates which they contained.

Crowther and Basu (13) (1931) in base exchange studies on the Woburn barley plots, found that the final replaceable calcium was reduced at the rate of 0.8 molecule of CaO per molecule of ammonium sulfate added throughout the experiment. "The relatively low value for the ammonium sulfate effect is due to the low base content of the very acid soils and the low calcium bicarbonate content of the water." To increase the replaceable calcium of the ammonium sulfate plots to that of the sodium nitrate plots required 2.8 mol. of CaO per mol. of ammonium sulfate when the lime was added at intervals of about 10 years. Most

of the added lime was recovered many years later when the original lime content was low, but this material was rapidly lost by leaching from soils of high replaceable calcium content.

In the above experiment there was no consistent evidence to indicate a depletion of exchangeable bases other than calcium as a result of sulfate of ammonia treatments. Nitrate of soda slightly increased exchangeable calcium, but exhibited no definite tendency toward increase in other bases, including sodium.

White (52) (1931) presented data on the soil acidity changes produced by ammonium sulfate at three rates of application on the Jordan plots. These were measured by a modified Jones' method on samples collected in the 29th, 34th and 40th years of the experiment. His data indicated that the net effect of one molecule of sulfate of ammonia is equal to only one molecule of dibasic soil acid under cropped conditions. This agrees with the concepts of Allison (2).

Merkle (24) (1934) made base exchange studies on the Jordan plots at the end of 50 years. Sulfate of ammonia reduced the exchangeable calcium, magnesium and potassium to a marked degree. However, the heaviest application (72 lbs. of nitrogen twice in each five-year rotation) did not cause a significant depletion of these bases as compared with the intermediate application (48 lbs.). "It seems logical that the more calcium that is present in the soil, the more rapidly it will be removed, and that, when the active content is reduced to a very low figure, the nitric and sulfuric acid may leach through as acids or even as iron or alumina salts. During the 12-year period from 1915 to 1927, the loss of calcium and magnesium has been no greater on the sulfate of ammonia plot 32 than on the phosphorus-potash plot 25. This is because early in the experiment the sulfate of ammonia has replaced the readily replaceable calcium with hydrogen ions."

In the above studies sodium nitrate was found to have no significant effect on the exchangeable bases, even at the highest rate of application. There was an apparent decrease in total base exchange capacity, as compared to nearby PK plots, on the basis of 1931 samples. Since this did not appear in the 1927 data, it is probably not significant.

Dried blood was somewhat less acid in its effects than sulfate of ammonia, but caused marked depletion of exchangeable calcium and magnesium, and corresponding increase in exchangeable hydrogen. In common with sulfate of ammonia, the higher rates were not proportionally effective.

Merkle concludes "that under field conditions it is not possible to determine, by calculation, how much lime is needed to counteract the acidity produced by sulfate of ammonia." This is of interest in contrast to White's data (52) on the same plots, which showed an almost perfect agreement with his theoretical calculations.

Tidmore and Williamson (47) (1932) gave base exchange data on soils treated with various nitrogenous fertilizers. A partial summary of their results is given in Table B.

TABLE B. EFFECT OF NITROGENOUS FERTILIZER ON EXCHANGEABLE BASES AND SOIL REACTION OF ALABAMA SOILS

	Milli-equivalents per 100 gm. of soil exchangeable					Final pH
	Ca	Mg	K	Total bases	H	
Norfolk s. l.—(cotton 6 yrs.)						
No N	.94	.024	.12	1.08	1.65	5.3
45 lbs. N per A. per yr.						
as $NaNO_3$	1.09	.023	.12	1.23	1.75	5.5
as $(NH_4)_2SO_4$	.29	.027	.06	.38	1.95	4.6
as urea	.91	.025	.04	.97	1.90	5.2
as cottonseed meal	1.24	.016	.11	1.37	1.98	5.2
Cecil c. l.—(cotton 6 yrs.)						
No N	3.31	.09	.34	3.74	1.30	5.9
45 lbs. N per A. per yr.						
as $NaNO_3$	3.40	.09	.40	3.89	.81	6.3
as $(NH_4)_2SO_4$	2.00	.42	.31	2.73	3.30	4.8
as urea	3.04	.08	.33	3.45	2.26	5.6
Cecil s. l.—(cotton 7 yrs.)						
No N	1.56	——	——	——	——	5.04
61.5 lbs. N per A. per yr.						
as $NaNO_3$	2.05	——	——	——	——	5.36
as $(NH_4)_2SO_4$	0.60	——	——	——	——	4.22

The preceding data demonstrate convincingly the marked depletion of exchangeable calcium resulting from ammonium sulfate. Urea shows the same tendency to a lesser degree. Cottonseed meal in the one case when it was tried did not decrease the exchangeable calcium, but did increase exchangeable hydrogen and acidity to a slight degree. Nitrate of soda in all cases increased the exchangeable calcium and decreased the acidity. There was no consistent effect upon exchangeable magnesium and potassium.

Lyon and Bizzell (23) (1933) studied the composition of drainage water and crops from lysimeters treated with nitrate of soda and sulfate of ammonia. In harmony with most previous work, more nitrogen and less calcium were leached from the former treatment. The sulfate of ammonia supplied less nitrogen and more calcium to the crop, in spite of a lower yield of dry matter than on the nitrate of soda treatment.

Pierre (39) (1933), applying theoretical assumptions based on his previous work (37), developed laboratory methods for determining the equivalent acidity or basicity of nitrogenous and other fertilizers of mixed composition. Thus in case of an organic material such as cottonseed meal, the alkalinity due to its ash residues is measured, and due allowance made in calculating the net effects of the fertilizer.

Moyer (31) (1934) found no immediate increase in acidity as a result of application of ammonium sulfate to a Sassafras loam soil at 5.4 pH. The acidity then increased progressively from the first to the sixtieth day after application, under uncropped conditions, without leaching. A reaction of 4.4 pH was then reached. Subsequent cropping with corn to remove excess nitrates decreased acidity to 4.9 pH. On the other hand, urea caused an immediate rise in pH, to 6.1 in 24 hours and 4 days. Cropping partially restored the reaction to 5.1 pH.

In addition to the previously cited investigations which included data on theoretical observations in regard to the effects of urea, Brioux (7) (1924) has made special studies of this material. It was found to act as an alkali in the soil at first, due to its rapid transformation to ammonium carbonate, but as it was nitrified, its action became that of an acid-reacting substance.

Allison (1) found increasing acidity from cottonseed meal, but to a lesser degree than in the case of nitrogen as ammoniates. Pierre's (39) data, employing his laboratory method, give this material a net equivalent acidity of 28.5 lbs. of $CaCO_3$ per unit of nitrogen, as compared with 35 lbs. for dried blood, 36 lbs. for urea and 107 lbs. for ammonium sulfate.

The following comments of Bear (6) (1929) are pertinent to the subject of evaluation of the effects of nitrogenous fertilizers upon the soil:

> "With the continued action of water and the various acid solvents that it may contain, soils in humid regions reach a point of equilibrium as to the hydrogen-ion content of their solutions and very little permanent increase in this case may be effected. The quantity of limestone required to be added to neutralize the acid effect of an application of an acidulating carrier of nitrogen is, therefore, also dependent upon the degree to which the soil complex has already been depleted of its basic constituents. Most of the cropping in humid climates is on soils the pH of which is between 5 and 6. Under these conditions it seems entirely safe to assume, both from theoretical and experimental ground, that not more than 2 or 3 pounds of calcium carbonate will normally be required to be applied to an acid soil to counteract the increase in acidity resulting from the use of a pound of nitrogen in the form of ammonium sulfate."

Expected Soil Effects Resulting from Nitrogenous Fertilizers, Based on Previous Investigations and Theories

That fertilizer constituents supplying nitrogen as ammonium salts have an acid effect upon the soil is clearly established. In all cases where soil changes resulting from the use of such materials have been studied, one or more of the following phenomena were exhibited:

a. Increase in hydrogen-ion concentration of the soil (decrease in pH).
b. Increase in exchangeable hydrogen.
c. Decrease in the exchangeable bases, especially calcium.
d. Increase in easily soluble aluminum, iron or manganese.

Except on soils containing large reserves of calcium carbonate, such as the heavily chalked soil at Rothamsted, England, these results are readily measured within a short time, when substantial annual applications are made.

Analyses of drainage waters have shown that the use of ammonium sulfate or similar salts has resulted in increased outgo of calcium and other bases from soils of humid regions. Such a result is sufficient explanation of the acid effects of a material which supplies no stable base.

Under uncropped conditions, the expected acidity resulting from an application of sulfate of ammonia is readily computed. Such a calculation assumes that all the ammonia will be nitrified in the soil, and that all the resulting nitrates, as well as the sulfates, will be removed by leaching in combination with bases withdrawn from the base exchange complex. No definite evidence has been offered in previous investigations to give complete support to these assumptions.

Increased acidity has been found to be the immediate result of an application of sulfate of ammonia. Under uncropped conditions, as nitrification proceeds, the pH of the soil continues to decrease, attaining a minimum when the nitrate content of the soil is at a maximum. Subsequent removal of nitrates from the soil, either by leaching, as in Swanback and Morgan's (46) results, or by crop removal, as in Moyer's (31) experiment, has in both cases increased the pH. However, the final values have been definitely more acid than that existing prior to treatment.

Under cropped conditions, the increased acidity residual from continued use of sulfate of ammonia has in no case been as great as the theoretical value based on production of both nitric and sulfuric acid in the soil. It has been variously evaluated, ranging from one molecule of dibasic acid per molecule of ammonium sulfate, up to substantially one and one-half molecules, on the same basis. Obviously the maximum theoretical acidity is two molecules. Measurements of the entire soil profile have failed to account for more than three-fourths of this theoretical value.

A simple and apparently reasonable explanation for the above discrepancy is to be found in the predominance of acids taken up by the crop, when nitrogen is grouped with sulfur, phosphorus, chlorine and other indisputably acidic constituents. Pierre (37), chiefly on the basis of pot experiments under cropped conditions without leaching, has developed an assumption that only one-half of the nitrogen added in the fertilizer is potentially acid, if the nitrogen thus applied is removed in the crop. The inexactness of this conclusion, based on Pierre's own data, has been pointed out by Allison, as previously stated.

On the other hand, physiological acidity in the true sense may possibly result from the withdrawal of the ammonium ion by crop or microorganism when ammonium sulfate has been recently applied to the soil. Under cropped conditions without leaching, the maximum theoretical physiological acidity is one molecule of dibasic acid per molecule of ammonium sulfate. However, under normal field conditions the process of nitrification proceeds so rapidly that this is probably an insignificant factor.

In general, urea has been found to be less than half as acid in its measurable acid effects upon the soil. The immediate result of its application is in an alkaline direction, doubtless due to the formation of ammonium carbonate. Under uncropped conditions, with complete nitrification and leaching of resultant nitrates, the maximum theoretical acid effects are one-half that of equivalent amounts of nitrogen as sulfate of ammonia. Allison (2) has concluded that under cropped conditions, with all of the nitrogen removed by the crop without any increase in base intake, urea would produce no acidity. In practice, the residual effect of this material is unquestionably acid.

Except for the slight theoretical basicity due to its ash constituents, cottonseed meal is potentially as acid as urea. However, probably due to its slower and more incomplete nitrification, both temporary and residual acidity resulting from its use have been less than from urea, in those comparisons which have been made. In combination with the non-nitrogenous materials needed to furnish a properly balanced complete fertilizer, its acid effect is rarely observed.

Nitrate of soda, under uncropped conditions, with complete removal of nitrates by leaching, is theoretically neutral in its effects. However, due to the development of more highly ionized exchange acidity, its temporary effect may be acid. In all cases where such studies have been made under cropped conditions, it has definitely decreased the degree of acidity. Its maximum physiological basicity is the equivalent of one-half pound of calcium oxide per pound of nitrogen. This has not been attained in practice. Pierre's assumption that one-half of the nitrogen applied is functionally acid, is a fair approximation of results usually obtained.

A factor which has not been generally recognized is a probably abnormal increase in pH in relation to the decrease in exchangeable hydrogen as a consequence of increased proportions of monovalent cations. The physical effects of continued liberal applications of this material have evidenced such a tendency. However, since sodium is only lightly absorbed by the base-exchange complex, this factor is of minor importance under humid soil conditions at normal rates of application.

PLAN OF INVESTIGATION

The four soils selected for this study are representative of major soil types in the Connecticut Valley. They are as follows:

> *Enfield very fine sandy loam:* This soil is a mellow, structureless, fine sandy loam of light brown color. It is derived from a thin mantle of post-glacial loess overlying gravel and till deposits. It is of limited occurrence, found chiefly on the rolling hills east of the broader Connecticut Valley glacial outwash terraces. This soil makes very high grade tobacco land, and also is especially well adapted to potatoes and other intensively cultivated crops.
>
> *Merrimac loamy sand:* This soil is a porous, structureless coarse sand of dark brown color. It is derived from a deep, stratified, coarse sand deposit comprising one of the higher glacial outwash terraces of the Connecticut Valley. Although too low in moisture-holding capacity for most crops, it has been extensively planted to "shade" tobacco during the past 25 years.
>
> *Wethersfield loam:* This soil is a firm, soft, granular loam, or clay loam, of red-brown color. It is developed from glacial till deposits derived chiefly from Triassic red shales. It is somewhat too heavy in texture to produce high-quality cigar wrapper tobacco, and is more extensively used for grass hay, corn and late vegetable crops.

Merrimac sandy loam: This soil is a dense, structureless sandy loam of medium brown color. It is derived from the deep stratified medium sand deposits which represent the major portion of the more extensive glacial outwash terraces of the Connecticut Valley. This soil is commonly used for tobacco of all three of the types grown in the section (Havana seed, Broadleaf and "Shade"). It is also moderately well adapted to potatoes and early vegetable crops.

More detailed descriptions of these types have been presented by the writer previously (26).

Comparative data with respect to pertinent soil characteristics, determined on samples of the original soil placed in the lysimeter in 1929, are given in Table 1.

TABLE 1. PHYSICAL AND CHEMICAL CHARACTERISTICS OF WINDSOR LYSIMETER SOILS AT TIME OF COLLECTION FROM THE FIELD, 1929

		Enfield v.f.s.l.	Merrimac l. s.	Wethersfield l.	Merrimac s. l.
Mechanical analyses					
Total material					
over 2 mm.	%	0.8	1.7	12.9	1.2
under 2 mm.	%	99.2	98.3	87.1	98.8
Material under 2 mm.					
Total sands	%	45.4	84.0	41.4	77.0
Silt	%	41.0	10.2	32.6	15.0
Clay (.005 mm.)	%	13.6	5.8	26.0	8.0
Clay (.002 mm.)	%	11.6	4.9	19.1	6.8
Volume weight*		1.18	1.40	1.37	1.49
Total water holding capacity (oven dry basis)	%	38.9	20.6	30.9	23.8
Moisture equivalent	%	15.7	6.1	18.6	9.6
Nitrogen-total in 2 mm. soil	%	.118	.045	.114	.073
Organic matter	%	3.00	1.40	2.20	1.55
Carbon-nitrogen ratio		15.5:1	16:1	11:1	12:1
Soil reaction (pH)		4.70	4.99	5.44	5.17
Base unsaturation	%	78.4	71.0	44.4	61.4
In milli-equivalents per 100 gm. of 2 mm. soil:					
Total base exchange capacity	—	6.91	3.24	7.95	5.13
Exchangeable hydrogen					
Determined	—	5.42	2.30	3.53	3.15
By difference	—	5.46	2.45	3.43	2.99
Exchangeable bases					
Calcium	—	.867	.405	3.493	1.503
Magnesium	—	.148	.018	.543	.206
Potassium	—	.375	.199	.293	.388
Sodium	—	.056	.169	.191	.044
Manganese	—	.035	.013	.100	.087

*As determined in place in the lysimeter tanks after thorough settling.

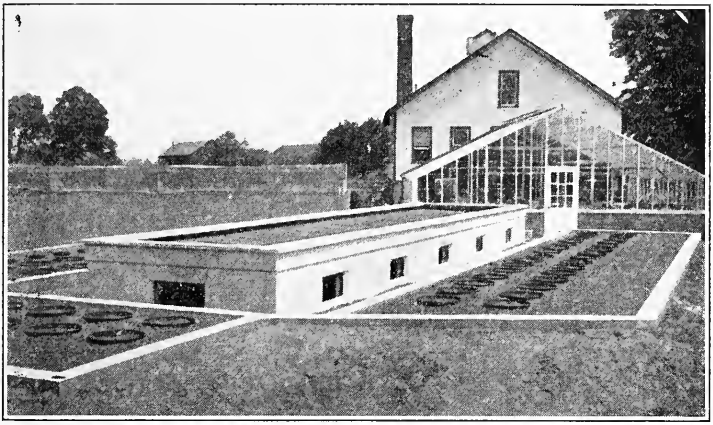

FIGURE 122. Windsor lysimeters, exterior view.

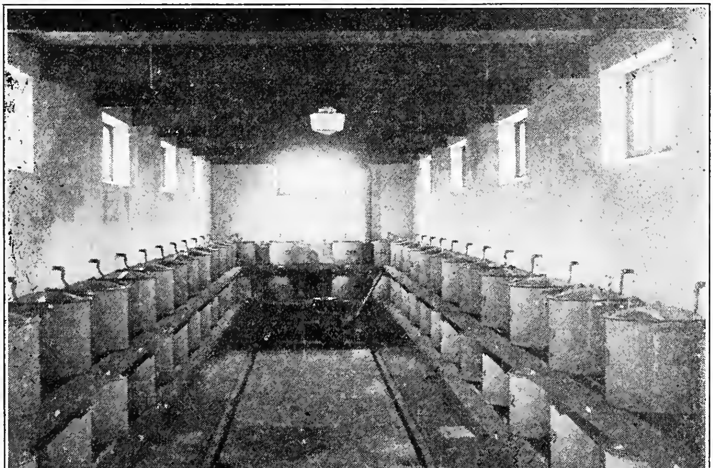

FIGURE 123. Windsor lysimeters, interior of collecting chamber.

The general arrangement of the lysimeter equipment* is shown in Figures 122 and 123. A protective fence has been installed since these photographs were taken in 1929. (See frontispiece).

With one exception, the soils used were from tobacco fields which had been under continuous culture to this crop for many years. The Wethersfield loam was taken from a grass hay field which had been occasionally planted to tobacco in recent years.

The above soils were placed in the lysimeter tanks in May, 1929. These tanks were cylindrical in shape, 9 inches deep and 20 inches in diameter, with a conical bottom filled with pure quartz sand, and an outlet tube of tin-lined pipe leading to the interior of the collecting chamber. The soil was taken from the upper 7 inches of surface of the fields, screened through one-third inch hardware cloth, thoroughly mixed and transported directly to the lysimeters. An amount producing an approximately 7-inch depth of firm soil was placed in each tank.

The amounts of soil used in the tanks, on a dry-weight basis, were as follows:

	Lbs. per Tank	Lbs. per acre of total soil	Lbs. per acre of 2 mm. soil
Enfield very fine sandy loam	80.8	1,616,000	1,604,000
Merrimac loamy sand	99.5	1,990,000	1,956,000
Wethersfield loam	90.7	1,814,000	1,580,000
Merrimac sandy loam	102.7	2,054,000	2,030,000

The fertilizer treatments were applied in dry form, mixed thoroughly with the upper 2 or 3 inches of soil, on May 26 of each year of the experiment. Each treatment was in duplicate on opposite sides of the collecting chamber.

The schedule of applications is given in Table 2.

*Valuable suggestions for the design and construction of this equipment were contributed by Dr. W. H. McIntire, Tenn. Agr. Expt. Sta.

TABLE 2. SCHEDULE OF ANNUAL FERTILIZER TREATMENTS
WINDSOR LYSIMETERS, SERIES A, 1929-1935

Sodium nitrate Tanks		Pounds per acre				
Nos. 1,2,9,10,17,18,25,26	Material	N	P_2O_5	K_2O	CaO	MgO
Nitrate of soda	1302.0	200				
Precipitated bone	232.4		100		90	
Carbonate of potash	155.2			100		
Sulfate of potash	206.8			100		
Carbonate of magnesia						
1929, 1930	52.3					25
1931, 1932, 1933	104.6					50
Ammonium sulfate Tanks						
Nos. 3,4,11,12,19,20,27,28						
Sulfate of ammonia	958.6	200				
Precipitated bone	232.4		100		90	
Carbonate of potash	155.2			100		
Sulfate of potash	206.8			100		
Carbonate of magnesia						
1929, 1930	52.3					25
1931, 1932, 1933	104.2					50
Urea Tanks						
Nos. 5,6,13,14,21,22,29,30						
Urea	435.6	200				
Precipitated bone	232.4		100		90	
Carbonate of potash	155.6			100		
Sulfate of potash	206.8			100		
Carbonate of magnesia						
1929, 1930	52.3					25
1931, 1932, 1933	104.2					50
Cottonseed meal Tanks						
Nos. 7,8,15,16,23,24,31,32						
Cottonseed meal	3006.0	200	94.6	58.6	9.0	21.0
Precipitated bone	14.9		6.4		5.7	
Carbonate of potash	109.8			70.7		
Sulfate of potash	146.4			70.7		
Carbonate of magnesia						
1929, 1930	8.4					4.0
1931, 1932, 1933	60.7					29.0

Tanks 33 and 34, of Merrimac sandy loam, received no nitrogenous fertilization, but all other materials were the same as for nitrate of soda tanks.

Table 3 summarizes the total applications of the various elements during the five years of the experiment, for each treatment. Amounts supplied in the rainfall are computed from analyses of water collected from "rain-gauge" tanks similarly placed and of the same diameter.*

* The amounts supplied by precipitation are estimated from data for the last three years of the experiment, since the rain-gauge tanks were not installed until 1931.

TABLE 3. QUANTITIES OF VARIOUS ELEMENTS ENTERING SOIL DURING FIVE-YEAR PERIOD 1929-1934—WINDSOR LYSIMETERS
(In pounds per acre)

Treatment series	N	P	K	Ca	Mg	S	Na	Cl
Sodium nitrate								
from fertilizer	1000.0	218.3	830.1	321.6	120.6	205.0	1653.1	44.1
from rainfall	22.4	——	27.6	61.2	13.3	84.9	53.0	54.4
Total	1022.4	218.3	857.7	382.8	133.9	289.9	1706.1	73.9
Ammonium sulfate								
from fertilizer	1000.0	218.3	830.1	321.6	120.6	1349.8	——	24.6
Total	1022.4	218.3	857.7	382.8	133.9	1434.7	53.0	79.0
Urea								
from fertilizer	1000.0	218.3	830.1	321.6	120.6	205.0	——	24.6
Total	1022.4	218.3	857.7	382.8	133.9	289.9	53.0	79.0
Cottonseed meal								
from fertilizer	1000.0	218.3	830.1	52.8	120.6	149.3	——	17.5
Total	1022.4	218.3	857.7	114.0	133.9	234.2	53.0	71.9
No nitrogen								
from fertilizer	——	218.3	830.1	321.6	120.6	205.0	——	24.6
Total	22.4	218.3	857.7	382.8	133.9	289.9	53.0	79.0

Since crop intake was not to be studied, and shallow tanks (with surface soil only) would be abnormally depleted of moisture by a growing crop, the soils were kept under fallow conditions. Leachings were collected after each rainfall producing drainage water. Samples were taken for immediate determination of nitrates, and aliquots were taken for a composite of all the leachings during six-month periods. These were: Summer-Fall (S-F)—May 26 to Nov. 25, incl.; and Winter-Spring (W-Sp) —Nov. 26 to May 25, incl.

A small amount of toluene was added to the bottles containing the composites to prevent biological activity during storage.

The amounts of drainage water collections, by periods, for the various soils, in relation to rainfall, are presented in Table 4.

The rainfall was considerably below normal except during the fourth year. The mean annual rainfall for 62 years preceding 1929, at Hartford, Conn., six miles south of the lysimeters, was 44.07 inches, with 21.08 inches between May 26 and November 25, and 22.99 inches between November 26 and May 25.

Data as to distribution of rainfall explain the marked differences in percentage of rainfall leached during the same periods for the various years. Precipitation occurring as a series of heavy rains produces much more leaching than when falling as light showers at more regular intervals. A similar factor operates to produce the greater divergence of percentages of rainfall leached on the different soils during the summer and fall months. Rainfall which occurs after all of the soils have become saturated is leached from one type in nearly as great a quantity as from another. On the other hand, the accumulated moisture de-

ficiency during dry periods, especially in summer, is dependent upon soil type, as affected by the moisture holding capacity and the rate of evaporation.

TABLE 4. DRAINAGE AND RAINFALL DATA — WINDSOR LYSIMETERS, SERIES A,1929-34

	Average Drainage								
	Enfield v.f.s.l.		Merrimac l.s.		Wethersfield l.		Merrimac s.l.		Rainfall
	inches	% of rainfall	inches	% of rainfall	inches	% of rainfall	inches	% of rainfall	inches
1929–1930									
*S—F	2.92	18.2	5.89	36.7	3.85	24.0	4.67	29.1	16.05
W—Sp.	5.80	33.2	7.73	44.3	6.67	38.2	6.42	36.8	17.45
Year	8.72	26.1	13.62	40.7	10.52	31.5	11.09	33.2	33.50
1930–1931									
S—F	3.32	20.7	5.27	32.8	4.41	27.5	4.65	29.0	16.04
W—Sp.	7.48	38.1	7.13	36.4	7.65	39.0	7.32	37.3	19.59
Year	10.80	30.3	12.40	34.8	12.06	33.9	11.97	33.6	35.63
1931–1932									
S—F	3.79	25.2	5.29	35.2	4.45	29.6	4.61	30.7	15.03
W—Sp.	9.87	57.5	12.21	71.2	11.07	64.5	11.20	65.3	17.14
Year	13.66	42.5	17.50	54.4	15.52	48.3	15.81	49.2	32.17
1932–1933									
S—F	8.57	32.2	11.78	44.3	10.37	39.0	10.46	39.3	26.58
W—Sp.	12.58	69.3	14.27	78.6	15.23	83.9	14.71	81.1	18.14
Year	21.15	47.4	26.05	58.4	25.60	57.3	25.17	56.4	44.72
1933–1934									
S—F	2.91	18.7	4.30	27.6	3.49	22.4	3.79	24.3	15.57
W—Sp.	6.89	37.8	8.38	46.0	6.85	37.6	6.79	37.3	18.20
Year	9.80	29.0	12.68	37.5	10.34	30.6	10.58	31.3	33.77
1929–1934									
S—F	21.51	24.1	32.53	36.4	26.57	29.8	28.18	31.6	89.27
W—Sp.	42.62	46.9	49.72	54.7	47.47	52.2	46.44	51.1	90.52
Five year total	64.13	35.9	82.25	46.1	74.04	41.5	74.62	41.8	179.79

During the last two years of the experiment, a separate study included uncropped lysimeter tanks of 20 and 30-inch depths, containing soil and subsoil of the Merrimac sandy loam, used in surface soil tanks 25–34. Leachings from 20 and 30-inch tanks were 87.2 per cent and 96.7 per cent respectively, of the volume percolating through the surface soil. The less effective "hydrostatic pull" of the short soil column is probably the factor causing decreased leaching from the 20-inch depth, as compared with the 30-inch tanks. On the other hand, the surface soil tanks, after the 7-inch depth of soil which they contain becomes practically dry, can lose little additional water. Evidently the greater total moisture deficit in the 30-inch soil column before precipitation begins, practically compensates for the increased moisture content of the surface soil in the shallow lysimeters after percolation has ceased.

More detailed presentation of the distribution and amounts of leaching in relation to precipitation, rate of evaporation and soil type will be reserved for a future paper.

*Here and in later tables, the following forms will be used: S-spring; F-fall; W-winter; Sp.-spring

Methods for analysis of the leachates. At the end of each six-month period, the composite samples of the leachates were brought to the soils laboratory at the Connecticut Agricultural Experiment Station at New Haven. The analytical work was done under the author's direction, assisted by H. G. M. Jacobson, a member of the scientific staff.* The following determinations were made by the methods stated:

Calcium, by precpitation as the oxalate, and subsequent volumetric analysis, by $KMnO_4$ titration, using substantially the A. O. A. C. method (32).

Magnesium, by precipitation as magnesium ammonium phosphate, and subsequent determination either gravimetrically, by the A. O. A. C. method, or volumetrically by the method of Handy (18).

Potassium, by precipitation as the chlorplatinate by the A. O. A. C. method (32).

Sodium, by precipitation as the Uranyl lead acetate, using the method of Williams (54).

Ammonia nitrogen, by distillation and subsequent Nesslerization or titration, depending upon amounts present, by the A. O. A. C. methods (32).

Manganese, colorimetrically, using potassium periodate to develop the permanganate color, by the method of Willard and Greathouse (53).

Aluminum, colorimetrically, using the aurintricarboxylic acid reagent, as proposed by Winter, Thrun and Bird (55).

Nitrate nitrogen, colorimetrically, with phenoldisulfonic acid by the A. O. A. C. method (32).

Sulfates, gravimetrically, as barium sulfate, by the A. O. A. C. method (32).

Bicarbonates, by titration with potassium hydrogen sulfate, using methyl orange as the indicator,by the A.O.A.C. method (32).

Chlorides, by titration with standard silver nitrate, using potassium chromate as the indicator, by the A. O. A. C. method (32).

Phosphates, colorimetrically, as the ceruleo-molybdate, using an adaptation of Truog's (48) method for phosphorus in soils.

pH, colorimetrically, checked with the glass electrode in 1933-34 by the method of DeEds (14).

During the first year of the experiment, preliminary qualitative tests for soluble iron in the leachates showed only small traces, less than two

* Collection of lysimeter leachates, fertilizer applications and periodic determinations of nitrates, by Dr. O. E. Street, Tobacco Substation. Windsor.

parts per million. Hence, no quantitative measurement of this element was made.

Silicates were not determined, since the author's laboratory facilities did not provide an adequate supply of platinum ware necessary for exact measurement of this constituent.

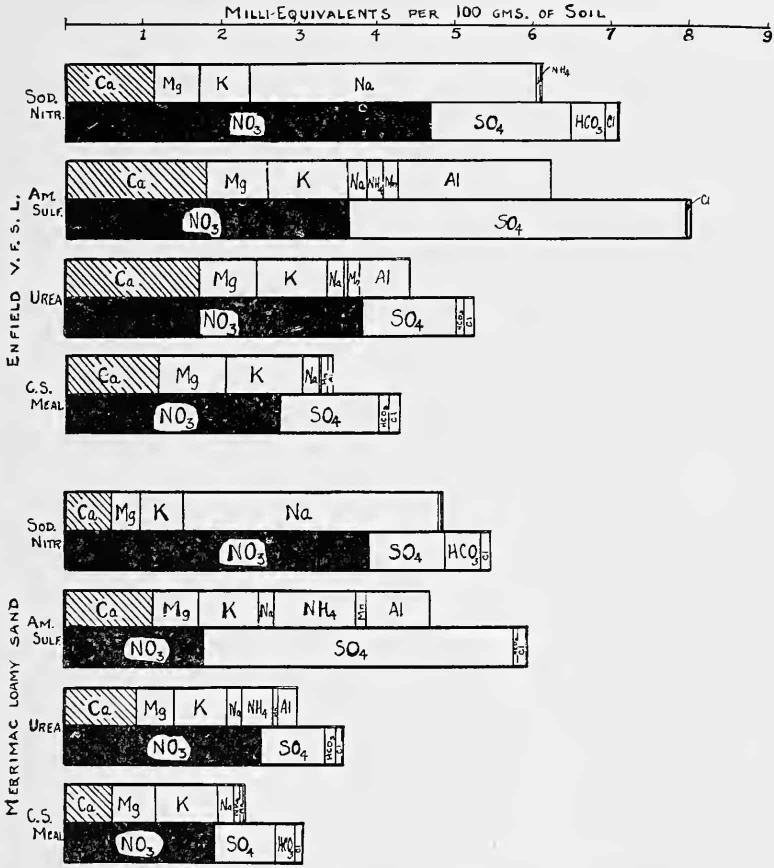

FIGURE 124. Balance of basic and acidic constituents, removed in drainage water during five-year period, Windsor lysimeters, Series A.—Wethersfield loam and Merrimac sandy loam soils.

METHODS OF SOIL STUDY. Samples of the original lysimeter soils were stored in closed containers until the end of the experiment. In May, 1934, the soils in the tanks were removed, thoroughly mixed and sampled.

Portions of both the original and final soil samples, passed through a 2-mm. screen, were examined for exchangeable bases, using the methods of Schollenberger and Dreibelbis (44). Exchangeable hydrogen and total base exchange capacity were measured by the method of Pierre and Scarseth (40).

Measurements of pH were made in April and November during the course of the experiment, and upon the final samples. The quinhydrone method was used and was found to give reliable results with all of the soils when checked by the glass electrode.

Finely ground (100-mesh) samples were also analyzed for total nitrogen and total carbon. Other determinations will be made when time permits, but are not expected to contribute to the present phase of the investigation.

PRESENTATION OF RESULTS

Results of analyses were first recorded in terms of parts per million (p. p. m.) in the leachate. This was then calculated to pounds per acre of surface soil, using the following formula:

$$\text{Lbs. per acre} = \text{p.p.m.} \times (\text{inches of leachate}) \times .226162$$

In order to show relationships of leachate data to changes in the soil, it was found desirable to recalculate to the basis of milli-equivalents per 100 gms. of 2 mm. soil. Since the weights of soil in the tanks of each series were different, the following formula was used:

$$\begin{array}{c}\text{milli-equivalents}\\ \text{per 100 gm. of}\\ \text{2 mm. soil}\end{array} = \frac{100{,}000}{\begin{array}{c}\text{lbs. per acre of}\\ \text{2 mm. soil}\end{array} \times \begin{array}{c}\text{equivalent ionic}\\ \text{weight}\end{array}}$$

Tables given in the appendix show complete data in pounds per acre for the average of duplicate tanks in the series, with respect to the various constituents during each six-month period. These form the basis of calculation for tabulations in terms of milli-equivalents per 100 gms. of soil.

Equilibria of Determined Basic and Acidic Constituents in the Leachate

Calculations of results in terms of milli-equivalents per 100 gms. of soil permit summations of basic and acidic constituents in the drainage water. Results of this tabulation by years are shown in Table 5. For simplification, data for the "no nitrogen" Merrimac sandy loam treatment is omitted from this table. Total basic and acidic constituents, in terms of milli-equivalents per 100 gms. of soil, for the five years, were as follows, in this case: basic—2.270; acidic—2.545; surplus (acidic)—.275.

A summary of the various basic and acidic constituents leached during the five-year period is shown graphically in Figures 124 and 125.

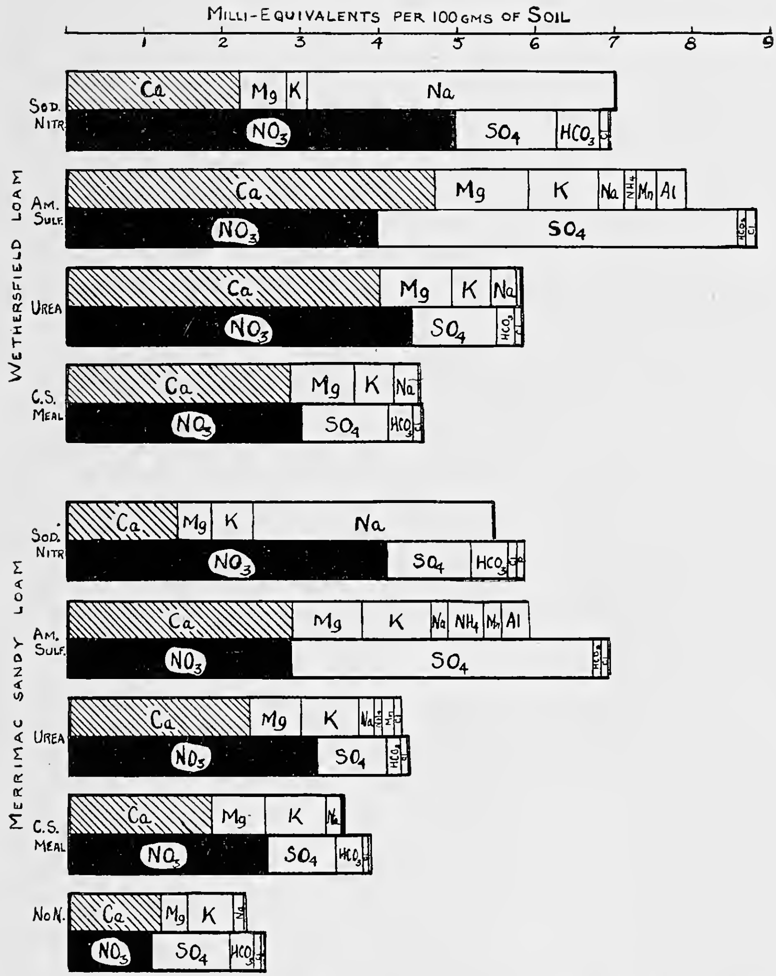

FIGURE 125. Balance of basic and acidic constituents removed in drainage water during five-year period, Windsor lysimeters, Series A.—Enfield v.f.s.l. and Merrimac loamy sand soils.

TABLE 5. TOTALS OF DETERMINED BASIC AND ACIDIC CONSTITUENTS IN THE LEACHATES WINDSOR LYSIMETERS, SERIES A
(In milli-equivalents per 100 gm. of soil)

	Sodium nitrate		Ammonium sulfate		Urea		Cottonseed meal	
	Basic	Acidic	Basic	Acidic	Basic	Acidic	Basic	Acidic
Enfield v.f.s.l.								
'29-'30	1.006	1.328	1.103	1.154	.912	.880	.703	.780
'30-'31	1.257	1.460	1.563	1.784	1.018	1.061	.716	.819
'31-'32	1.235	1.408	1.643	1.811	.876	1.116	.817	1.037
'32-'33	1.417	1.605	1.053	2.005	.895	1.374	.721	1.010
'33-'34	1.190	1.284	.883	1.351	.704	.824	.488	.660
Five year total	**6.105**	**7.085**	**6.245**	**8.105**	**4.405**	**5.255**	**3.445**	**4.306**
Surplus		.980		1.860		.850		.861
Merrimac l. s.								
'29-'30	.974	1.011	.901	1.059	.587	.662	.497	.626
'30-'31	.901	1.122	.981	1.218	.504	.551	.367	.536
'31-'32	.928	1.089	1.048	1.175	.606	.694	.541	.683
'32-'33	1.074	1.145	.917	1.386	.684	.853	.509	.672
'33-'34	.958	1.097	.820	1.073	.592	.696	.402	.544
Five-year total	**4.835**	**5.464**	**4.667**	**5.911**	**2.973**	**3.456**	**2.316**	**3.061**
Surplus		.629		1.244		.483		.745
Wethersfield l.								
'29-'30	1.182	1.241	1.406	1.575	1.056	1.174	.884	.839
'30-'31	1.704	1.603	2.042	1.992	1.411	1.294	.914	.878
'31-'32	1.382	1.397	1.755	1.852	1.171	1.104	1.026	1.001
'32-'33	1.495	1.421	1.615	1.980	1.297	1.241	.924	.961
'33-'34	1.267	1.289	1.113	1.435	.904	1.026	.773	.891
Five-year total	**7.030**	**6.951**	**7.929**	**8.834**	**5.839**	**5.839**	**4.521**	**4.570**
Surplus	.079			.905				.049
Merrimac s. l.								
'29-'30	1.081	1.195	1.359	1.474	.913	1.029	.773	.910
'30-'31	1.094	1.232	1.344	1.545	.851	.917	.686	.798
'31-'32	1.090	1.192	1.154	1.242	.795	.754	.788	.806
'32-'33	1.158	1.225	1.190	1.532	.960	.944	.716	.720
'33-'34	1.043	1.018	.896	1.127	.686	.735	.592	.643
Five-year total	**5.466**	**5.862**	**5.906**	**6.920**	**4.205**	**4.379**	**3.555**	**3.877**
Surplus		.396		1.013		.174		.322

Unfortunately the plan of analysis, which was established before the possibilities of a study of this sort were fully realized, did not include determinations of either iron or silicic acid. Hence perfect agreement between anions and cations could not be expected. However, the undetermined ions were obviously low in relation to the other constituents.

Inspection of the data in Table 5 shows that on three of the four soils there is a constituent surplus of determined anions over cations on all treatments during practically every period. This surplus of anions attains a maximum in the case of the Enfield very fine sandy loam. Reference to Table 1 shows this soil to have the greatest initial acidity and highest degree of base unsaturation. Furthermore, the relative intensity of acidity of the original soils, as shown by pH and degree of base unsatura-

tion, is reflected in the magnitude of the surplus of determined acidic constituents. The excess of anions is greatest for the sulfate of ammonia treatments. This is in harmony with what one should expect if this apparent excess is due to either free acidity or to iron appearing as a cation in considerable amounts. Yet, this assumption fails to explain the greater surplus of acidic constituents for cottonseed meal as compared with urea, as well as the higher excess of anions under the nitrate of soda treatment, in comparison with urea.

The failure of the assumption that this excess of acidic constituents is due to either free acid or iron is apparent in comparing data as to reaction, aluminum, manganese and bicarbonate in the leachings, as shown in Table 6. In all cases it is seen that the leachates from the cottonseed meal treatment have been less acid, and have contained less aluminum and manganese and more bicarbonates than those from the urea tanks. Yet the excess of acidic constituents is consistently greater on the cottonseed meal tanks.

TABLE 6. SUMMARY OF LEACHINGS OF CONSTITUENTS RELATED TO SOIL REACTION WINDSOR LYSIMETERS, SERIES A, 1929-1934
(In milli-equivalents per 100 gm. of soil)

	(Averages of duplicate tanks)				
	Final pH of soil	Mean pH of leachate*	Aluminum	Manganese	Bicarbonates
Enfield v.f.s.l.					
Sodium nitrate	5.34	6.94	.010	.016	.443
Ammonium sulfate	4.03	4.32	1.976	.174	.014
Urea	4.45	4.67	.646	.133	.067
Cottonseed meal	4.49	5.63	.087	.061	.114
Merrimac l. s.					
Sodium nitrate	5.98	6.89	.007	.014	.447
Ammonium sulfate	4.64	4.71	.813	.112	.048
Urea	5.01	5.20	.245	050	.123
Cottonseed meal	4.99	6.67	.034	.054	.242
Wethersfield l.					
Sodium nitrate	6.22	6.68	.006	.001	.415
Ammonium sulfate	4.15	4.99	.383	.259	.134
Urea	4.89	6.34	.016	.036	.221
Cottonseed meal	5.03	6.40	.003	.002	.322
Merrimac s. l.					
Sodium nitrate	5.89	6.53	.008	.006	.476
Ammonium sulfate	4.12	4.84	.355	.239	.100
Urea	4.70	5.55	.089	.109	.181
Cottonseed meal	4.83	6.29	.010	.022	.338
No nitrogen	5.52	6.51	.004	.003	.371

There is a possibility that sodium was not completely recovered in the analysis of the leachates during the first two years. The method for sodium has been somewhat improved in the later years. As will be discussed below, the amount of sodium recovered in the leachates and as exchangeable sodium from the nitrate of soda tanks is less than

*Weighted average, on basis of H-ion concentration.

the expected amount in all cases. This discrepancy is practically the same as the apparent excess of anions in the drainage water from the nitrate of soda tanks, for all soils except the Wethersfield loam.

Zinc. At the time of emptying the tanks in the spring of 1934, it was noted that the circular discs of quarter-inch hardware cloth placed between the sand filter bed and soil had undergone some corrosion. These had been thoroughly painted with two coats of asphaltum before the tanks were filled in 1929. The corrosion was most noticeable on the discs under the sulfate of ammonia treatments, particularly on the two more acid soils (Enfield v.f.s.l. and Merrimac loamy sand). The hardware cloth was galvanized with zinc, and in some cases the iron core of the wire was completely exposed. There was no evident corrosion on the walls or bottoms of the tanks.

Later, the soils removed from the tank were used for pot experiments, growing tobacco under greenhouse conditions. It was soon apparent that soils unlimed in the pot tests produced plants of very abnormal appearance. This condition was most striking on the soils receiving sulfate of ammonia while in the lysimeter tanks, although exhibited to some degree on three of the nitrate of soda treatments. In the case of the Merrimac sandy loam, it appeared only on the sulfate of ammonia treatment.

Tests for zinc revealed the presence of abnormal concentration in both the soil and the crop, in all cases where the abnormal symptoms were manifest. The condition was fully corrected by liming with calcium carbonate in amounts sufficient to satisfy the laboratory determinations of exchangeable hydrogen. More detailed studies of this phenomenon will be reported in a later publication.

Unfortunately the possibility of zinc contamination was not foreseen, hence no tests for zinc in the drainage water had been made. However, it appears reasonable to assume that this cation was present in the leachate, and that this may have contributed largely to the apparent excess of anions.

Bases Added to the Soil in Relation to Outgo in Drainage

With the amounts of the various basic constituents entering the soil through the fertilizer (and brought down from the atmosphere by the rainfall) as a matter of record, the leachate data provide a measure of the changes which may be expected in the base status of the soil. Table 7 presents the additions of the respective bases, expressed in milli-equivalents per 100 gm. of 2 mm. soil. It is to be noted that the total bases added in the nitrate of soda treatments exceed the values for sulfate of ammonia and urea by an amount equivalent to the sodium as sodium nitrate. On the other hand, smaller amounts of bases are supplied by the cottonseed meal, in consequence of its lower ratio of calcium to phosphorus than in precipitated bone (chiefly dicalcium phosphate).

While the amounts of the various elements entering the soil are the same on an acre basis for corresponding treatments on each soil, differences in volume, weight, and percentage of fine soil (less than 2 mm.) result in the variations in amounts as computed in terms of milli-equivalents per 100 gm. of soil. Since the fertilizer material when applied is not coarser than 2 mm., and the gravel and coarse sand fragments may

be safely regarded as remaining unchanged during the five-year period of the experiment, all comparisons are on the basis of the soil which passes a 2 mm. screen.

TABLE 7. QUANTITIES OF BASES ENTERING SOIL DURING FIVE YEAR PERIOD, 1929-1934, WINDSOR LYSIMETERS, SERIES A
(In milli-equivalents per 100 gm. of soil)

	Potassium	Calsium	Magnesium	Sodium	Total
Enfield v.f.s.l.					
Sodium nitrate	1.372	1.191	.686	4.624	7.873
Ammonium sulfate	1.372	1.191	.686	.144	3.393
Urea	1.372	1.191	.686	.144	3.393
Cottonseed meal	1.372	.355	.686	.144	2.557
Merrimac l. s.					
Sodium nitrate	1.115	.976	.562	3.788	6.441
Ammonium sulfate	1.115	.976	.562	.118	2.771
Urea	1.115	.976	.562	.118	2.771
Cottonseed meal	1.115	.291	.562	.118	2.086
Wethersfield l.					
Sodium nitrate	1.389	1.210	.696	4.692	7.987
Ammonium sulfate	1.389	1.210	.696	.146	3.441
Urea	1.389	1.210	.696	.146	3.441
Cottonseed meal	1.389	.360	.696	.146	2.591
Merrimac s. l.					
Sodium nitrate	1.081	.942	.542	3.651	6.216
Ammonium sulfate	1.081	.942	.542	.113	2.678
Urea	1.081	.942	.542	.113	2.678
Cottonseed meal	1.081	.280	.542	.113	2.016
No nitrogen	1.081	.942	.542	.113	2.678

TABLE 8. SUMMARY OF LEACHINGS OF STABLE EXCHANGEABLE BASES DURING FIVE YEAR PERIOD 1929-1934, WINDSOR LYSIMETERS, SERIES A
(In milli-equivalents per 100 gm. of soil)

	(Averages of duplicate tanks)				
	Potassium	Calcium	Magnesium	Sodium	Total
Enfield v.f.s.l.					
Sodium nitrate	.664	1.150	.583	3.640	5.937
Ammonium sulfate	1.031	1.853	.770	.256	3.910
Urea	.895	1.744	.723	.214	3.576
Cottonseed meal	.990	1.221	.846	.216	3.273
Merrimac s. l.					
Sodium nitrate	.543	.610	.352	3.282	4.787
Ammonium sulfate	.778	1.149	.572	.198	2.697
Urea	.687	.932	.470	.188	2.277
Cottonseed meal	.783	.630	.558	.202	2.173
Wethersfield l.					
Sodium nitrate	.258	2.225	.602	3.915	7.000
Ammonium sulfate	.882	4.716	1.208	.326	7.132
Urea	.502	4.005	.928	.319	5.754
Cottonseed meal	.492	2.864	.820	.323	4.499
Merrimac s. l.					
Sodium nitrate	.544	1.413	.441	3.032	5.430
Ammonium sulfate	.871	2.897	.883	.212	4.863
Urea	.727	2.329	.661	.198	3.915
Cottonseed meal	.821	1.829	.680	.165	3.495
No nitrogen	.581	1.172	.351	.132	2.236

TABLE 9. RELATIVE LEACHING OF BASIC CONSTITUENTS DURING FIRST SIX MONTHS AFTER FERTILIZER APPLICATIONS AS COMPARED WITH SECOND SIX MONTHS WINDSOR LYSIMETERS, SERIES A

(Average of five years)

		milli-equivalents per 100 gm. of soil				Ratio to calcium Ca = 1		
		Ca	K	Mg	Na	K	Mg	Na
Enfield v.f.s.l.								
Sodium nitrate	1.	.825	.372	.442	2.842	.451	.536	3.445
	2.	.325	.292	.141	.798	.898	.434	2.455
Ammonium sulfate	1.	1.271	.473	.547	.155	.372	.430	.122
	2.	.564	.558	.223	.101	.989	.395	.179
Urea	1.	1.277	.456	.518	.133	.357	.405	.104
	2.	.467	.439	.205	.081	.940	.439	.173
Cottonseed meal	1.	.894	.459	.580	.129	.513	.649	.144
	2.	.327	.531	.266	.087	1.624	.813	.266
Merrimac l. s.								
Sodium nitrate	1.	.486	.388	.288	2.921	.798	.593	6.010
	2.	.124	.155	.064	.361	1.250	.516	2.911
Ammonium sulfate	1.	.917	.595	.471	.111	.649	.514	.121
	2.	.232	.183	.101	.087	.789	.435	.375
Urea	1.	.781	.494	.395	.085	.633	.506	.109
	2.	.151	.193	.075	.103	1.278	.497	.682
Cottonseed meal	1.	.486	.536	.434	.100	1.103	.893	.206
	2.	.144	.247	.124	.102	1.715	.723	.708
Wethersfield l.								
Sodium nitrate	1.	1.845	.138	.434	2.807	.075	.235	1.521
	2.	.380	.120	.168	1.108	.316	.442	2.916
Ammonium sulfate	1.	3.284	.493	.788	.191	.150	.240	.058
	2.	1.432	.389	.420	.135	.272	.293	.094
Urea	1.	3.028	.291	.664	.194	.096	.219	.064
	2.	.977	.211	.264	.125	.216	.270	.128
Cottonseed meal	1.	1.994	.267	.572	.198	.134	.287	.099
	2.	.870	.225	.248	.125	.259	.285	.144
Merrimac s. l.								
Sodium nitrate	1.	1.276	.377	.380	2.584	.295	.298	3.025
	2.	.137	.167	.061	.449	1.220	.445	3.270
Ammonium sulfate	1.	2.508	.581	.776	.135	.232	.309	.054
	2.	.389	.290	.107	.077	.746	.275	.198
Urea	1.	2.060	.468	.552	.124	.227	.268	.060
	2.	.269	.259	.109	.074	.963	.405	.275
Cottonseed meal	1.	1.525	.507	.544	.096	.332	.357	.063
	2.	.304	.314	.136	.069	1.033	.447	.227
No nitrogen	1.	.890	.311	.251	.061	.349	.282	.069
	2.	.282	.270	.100	.071	.957	.355	.252

The total amounts of the stable bases in the soil (Ca, Mg, K, and Na), leached from the soil during the five years, are given in Table 8. Comparisons between the amounts of the individual bases added and leached will be presented in connection with changes in the exchangeable bases in the soil.

Seasonal Leaching of Bases

Data on the relative leaching of bases during the two half-yearly periods yield certain interesting distinctions, as shown in Table 9. It is seen that the ratio between calcium and potassium is much wider in all cases during the first six-month period after fertilizer application than during the second six months (winter and spring), and the decrease in calcium is much greater than for potassium during the latter period. There is a much closer parallel between the relative amounts of calcium and nitrates in the respective periods. It may thus be implied that there is a greater tendency for calcium to leach in the form of nitrates, while potassium is better suited to pass through the soil in the form of sulfates and bicarbonates. It is probable that the presence of larger amounts of soluble calcium during the first six months has tended to repress the amount of potassium going into solution as potassium nitrate, in harmony with the findings of Peech and Bradfield (35). On the other hand, potassium is more readily soluble than calcium in combinations with sulfates and bicarbonates. In this connection it is to be noted that the larger amounts of calcium leached from the Wethersfield loam have been accompanied by smaller losses of potassium.

The ratio between calcium and magnesium is not significantly different in the two periods, for any of the soils. With the exception of the nitrate of soda treatment, the amount of sodium corresponding to calcium is higher during the winter-spring periods, on the average. Sodium leachings fall off more than calcium during the second period, as would be expected on the basis of their relative absorption in the base exchange complex. However, the reverse is true on the Wethersfield loam and Merrimac sandy loam soils.

Yearly Trends in Leaching of Bases

Data giving yearly leaching of the basic constituents, Table 10, show that calcium was leached to a greater degree during the first year and there has been a fairly consistent decrease in calcium outgo during the succeeding years. The severe leaching to which the soils were subjected in '32-'33 (Table 4) caused the actual calcium losses to be higher on most of the treatments, during this period than for the preceding year. It is to be noted that while the quantities of water leached during the first and fifth years are substantially the same on all soils, the amounts of calcium leached in many cases are less than one-half as much during the fifth year as during the first.

An obvious explanation is that this phenomenon is due to progressive depletion of the active calcium in the soil. As will be shown later, this is doubtless possible in all cases except on the Merrimac loam sand under both nitrate of soda and urea treatments. Yet in these instances, a decline in calcium leaching is also to be observed.

TABLE 10. YEARLY TRENDS IN LEACHING OF BASES—WINDSOR LYSIMETERS, SERIES A
(In milli-equivalents per 100 gm. of soil)

	Calcium					Potassium				
	29-30	30-31	31-32	32-33	33-34	29-30	30-31	31-32	32-33	33-34
Enfield v.f.s.l.										
Sodium nitrate	.320	.268	.201	.194	.167	.082	.110	.189	.177	.106
Ammonium sulfate	.583	.485	.253	.286	.227	.103	.214	.272	.273	.169
Urea	.516	.430	.242	.281	.275	.083	.150	.233	.273	.156
Cottonseed meal	.354	.313	.224	.209	.122	.089	.192	.305	.250	.153
Merrimac l. s.										
Sodium nitrate	.177	.132	.105	.104	.091	.065	.082	.141	.156	.096
Ammonium sulfate	.390	.196	.167	.234	.162	.082	.095	.182	.239	.179
Urea	.288	.126	.113	.216	.188	.064	.105	.162	.197	.153
Cottonseed meal	.230	.127	.098	.104	.072	.081	.120	.192	.221	.163
Wethersfield l.										
Sodium nitrate	.515	.589	.386	.388	.347	.019	.038	.066	.083	.052
Ammonium sulfate	1.079	1.515	1.075	.722	.326	.022	.105	.235	.336	.186
Urea	.754	1.068	.820	.836	.527	.021	.055	.084	.214	.128
Cottonseed meal	.582	.656	.661	.544	.420	.022	.050	.094	.192	.134
Merrimac s. l.										
Sodium nitrate	.365	.353	.270	.220	.205	.054	.079	.148	.163	.099
Ammonium sulfate	.925	.817	.491	.427	.237	.090	.127	.214	.277	.164
Urea	.607	.556	.403	.456	.308	.077	.095	.194	.220	.140
Cottonseed meal	.503	.417	.364	.299	.247	.081	.124	.247	.220	.149
No nitrogen	.302	.321	.218	.194	.137	.076	.097	.157	.156	.096

	Magnesium					Sodium				
	29-30	30-31	31-32	32-33	33-34	29-30	30-31	31-32	32-33	33-34
Enfield v.f.s.l.										
Sodium nitrate	.130	.107	.120	.124	.103	.447	.761	.720	.905	.808
Ammonium sulfate	.175	.172	.193	.116	.116	.060	.042	.062	.041	.031
Urea	.179	.114	.160	.161	.109	.067	.030	.058	.033	.025
Cottonseed meal	.145	.162	.196	.180	.163	.069	.036	.057	.030	.022
Merrimac l. s.										
Sodium nitrate	.047	.053	.082	.084	.087	.665	.628	.595	.714	.681
Ammonium sulfate	.060	.083	.140	.174	.114	.031	.034	.071	.033	.031
Urea	.047	.050	.092	.150	.131	.038	.020	.077	.032	.023
Cottonseed meal	.072	.086	.129	.138	.133	.045	.022	.079	.033	.023
Wethersfield l.										
Sodium nitrate	.126	.122	.122	.135	.097	.513	.949	.803	.884	.767
Ammonium sulfate	.178	.329	.250	.245	.206	.111	.050	.085	.048	.033
Urea	.133	.214	.185	.196	.199	.134	.051	.071	.035	.027
Cottonseed meal	.137	.151	.197	.145	.189	.135	.052	.071	.037	.028
Merrimac s. l.										
Sodium nitrate	.099	.078	.068	.087	.109	.549	.577	.598	.682	.625
Ammonium sulfate	.191	.154	.186	.234	.095	.043	.044	.065	.032	.022
Urea	.150	.095	.100	.177	.139	.047	.042	.057	.029	.022
Cottonseed meal	.132	.089	.128	.165	.165	.037	.040	.047	.024	.018
No nitrogen	.078	.072	.065	.063	.072	.021	.022	.044	.024	.018

It is probable that during the early years of the experiment, especially during the first year, the trend is toward replacement of calcium with potassium in the base exchange complex under the heavy rate of potash fertilization practiced. As the potash-absorbing power of the soil becomes satisfied, calcium is more fully retained by the soil. This is in harmony with the yearly trends with respect to potassium.

The potassium leaching shows a regular increase from year to year in practically all cases, until the last year. The decreased outgo in 1933-1934 is at least in part to be explained on the basis of less volume of leachate, the drainage in that year being less than half as much as in the previous year. As has been noted before, potassium continues to leach to a significant degree after most of the annual outgo of calcium and nitrates has been accounted for in the drainage. The leachings during the first and fifth years, similar in volume, show much greater potassium losses in the final year, this being the opposite of calcium results. As previously shown in Tables 7 and 8, potassium has been applied in excess of the amounts recovered in the leachate, in all cases. Hence, the trend toward increased outgo of potassium is not surprising.

Magnesium has shown no pronounced yearly trend. Only the Merrimac loamy sand showed larger magnesium leachings after the rate of application of this element was increased in 1931.

Table 11. Exchangeable Bases — Windsor Lysimeter Soils, Series A
(In milli-equivalents per 100 gm. of soil)

	Calcium	Magnesium	Potassium	Sodium	Manganese	Total
Enfield v.f.s.l.						
Sodium nitrate	.749	.274	.666	.185	.024	1.898
Ammonium sulfate	.315	.074	.293	.030	.005	.717
Urea	.452	.135	.452	.026	.013	1.078
Cottonseed meal	.393	.169	.423	.032	.028	1.045
Original soil	.867	.148	.375	.056	.035	1.481
Merrimac l. s.						
Sodium nitrate	.649	.240	.329	.115	.010	1.343
Ammonium sulfate	.328	.074	.121	.025	.001	.549
Urea	.400	.081	.167	.021	.003	.672
Cottonseed meal	.381	.106	.123	.022	.010	.642
Original soil	.405	.118	.199	.069	.013	.804
Wethersfield l.						
Sodium nitrate	2.155	.544	.932	.482	.047	4.160
Ammonium sulfate	.508	.113	.380	.029	.052	1.082
Urea	1.069	.193	.688	.034	.070	2.054
Cottonseed meal	1.338	.395	.703	.033	.076	2.545
Original soil	3.493	.543	.293	.191	.100	4.620
Merrimac s. l.						
Sodium nitrate	1.011	.187	.569	.184	.031	1.982
Ammonium sulfate	.405	.052	.190	.045	.008	.700
Urea	.609	.045	.348	.046	.044	1.092
Cottonseed meal	.580	.092	.340	.035	.044	1.091
No nitrogen	1.269	.229	.599	.033	.033	2.163
Original soil	1.503	.206	.388	.074	.087	2.258

Sodium has shown no consistent change from year to year, except that on the Wethersfield loam. On this soil, with a relatively high initial content of exchangeable sodium, there is a higher loss of this element by leaching, during the first than during subsequent years, in spite of the low volume of leaching in 1929-1930. Generally, higher sodium leachings in 1931-1932 are associated with higher chlorine and are explained by especially severe storms from the southeast which blew unusually large quantities of sea spray for great distances inland. This was confirmed by an analysis of the water from the rain-gauge tanks during this period. Windsor is approximately 40 miles north of Long Island Sound.

Exchangeable Bases in the Soils

Determinations of the stable exchangeable bases (calcium, magnesium, potassium and sodium) in the lysimeter soils were made on samples collected at the end of the five-year period, in comparison with the original soils. Data are shown in Table 11. Figures given represent averages of separate measurements for duplicate tanks, which agreed very satisfactorily.

TABLE 12. BASE EXCHANGE CAPACITY AND EXCHANGEABLE HYDROGEN
WINDSOR LYSIMETER SOILS, SERIES A
(In milli-equivalents per 100 gm. of soil)

	Total Base Exchange Capacity (T)	Sum of Exchangeable Bases (S)	Exchangeable Hydrogen by difference (T-S)	Exchangeable Hydrogen determined
Enfield v.f.s.l.				
Sodium nitrate	6.85	1.90	4.95	4.65
Ammonium sulfate	6.97	.72	6.25	6.60
Urea	6.81	1.08	5.73	6.11
Cottonseed meal	6.96	1.04	5.92	6.18
Original soil	6.91	1.48	5.43	5.42
Merrimac l. s.				
Sodium nitrate	3.25	1.34	1.91	2.02
Ammonium sulfate	3.41	.55	2.86	2.68
Urea	3.32	.67	2.65	2.36
Cottonseed meal	3.20	.64	2.56	2.27
Original soil	3.42	.80	2.62	2.30
Wethersfield l.				
Sodium nitrate	8.04	4.16	3.88	3.79
Ammonium sulfate	8.33	1.08	7.25	7.16
Urea	8.17	2.05	6.12	5.99
Cottonseed meal	7.95	2.55	5.40	5.26
Original soil	7.95	4.62	3.33	3.53
Merrimac s. l.				
Sodium nitrate	5.07	1.98	3.09	3.14
Ammonium sulfate	5.28	.70	4.58	4.80
Urea	5.17	1.09	4.08	4.35
Cottonseed meal	5.08	1.09	3.99	4.03
No nitrogen	5.14	2.16	2.98	3.28
Original soil	5.13	2.25	2.88	3.15

In all cases sulfate of ammonia has shown marked decreases in calcium, magnesium, and total bases as compared with the original soils. The urea treatment has resulted in less exchangeable calcium, has had no consistent effect upon magnesium (except for heavy loss on the Wethersfield soil), and has permitted some accumulation of exchangeable potassium on the Enfield and Wethersfield soils. Cottonseed meal, a treatment supplying less calcium, has resulted in a final exchangeable calcium content similar to that from urea. It has left magnesium practically unchanged, (except for loss on the Wethersfield soil), and has also permitted potassium accumulation in the two heavier-textured soils.

Sodium has shown some accumulation in the soils treated with nitrate of soda, and this has been proportional to the base exchange capacity of the soil. Nitrate of soda has resulted in calcium losses in all cases, which have been more than compensated by accumulations in magnesium, potassium, and sodium, on the more highly acid Enfield and Merrimac loamy sand soils. The accumulation of exchangeable potassium from the fertilizer has been at a maximum on the nitrate of soda treatments. Here, also, the residual exchangeable potassium has been proportional to base exchange capacity.

Results of determinations of total base exchange capacity and exchangeable hydrogen in relation to exchangeable bases are shown in Table 12.

TABLE 13. CORRELATIONS BETWEEN BASE SATURATION AND pH
WINDSOR LYSIMETER SOILS, SERIES A
(Final measurements at end of five year period)

		Percentage Base Saturation	pH
Enfield v.f.s.l.			
Sodium nitrate	—	27.3	5.34
Ammonium sulfate	—	10.7	4.03
Urea	—	15.6	4.45
Cottonseed meal	—	14.6	4.49
Original soil	—	20.1	4.70
Merrimac l. s.			
Sodium nitrate	—	41.1	5.98
Ammonium sulfate	—	16.1	4.64
Urea	—	20.2	5.01
Cottonseed meal	—	19.7	4.99
Original soil	—	24.4	4.99
Wethersfield l.			
Sodium nitrate	—	51.0	6.22
Ammonium sulfate	—	12.4	4.15
Urea	—	24.3	4.89
Cottonseed meal	—	31.1	5.03
Original soil	—	56.9	5.44
Merrimac s. l.			
Sodium nitrate	—	38.5	5.89
Ammonium sulfate	—	13.2	4.12
Urea	—	20.2	4.70
Cottonseed meal	—	20.6	4.83
No nitrogen	—	41.4	5.52
Original soil	—	41.2	5.17

The direct determinations of exchangeable hydrogen correspond closely with amounts calculated by difference between total bases and base exchange capacity.

There is evidence that the sulfate of ammonia causes an increase in base exchange capacity, since in all cases the final figures on this treat-

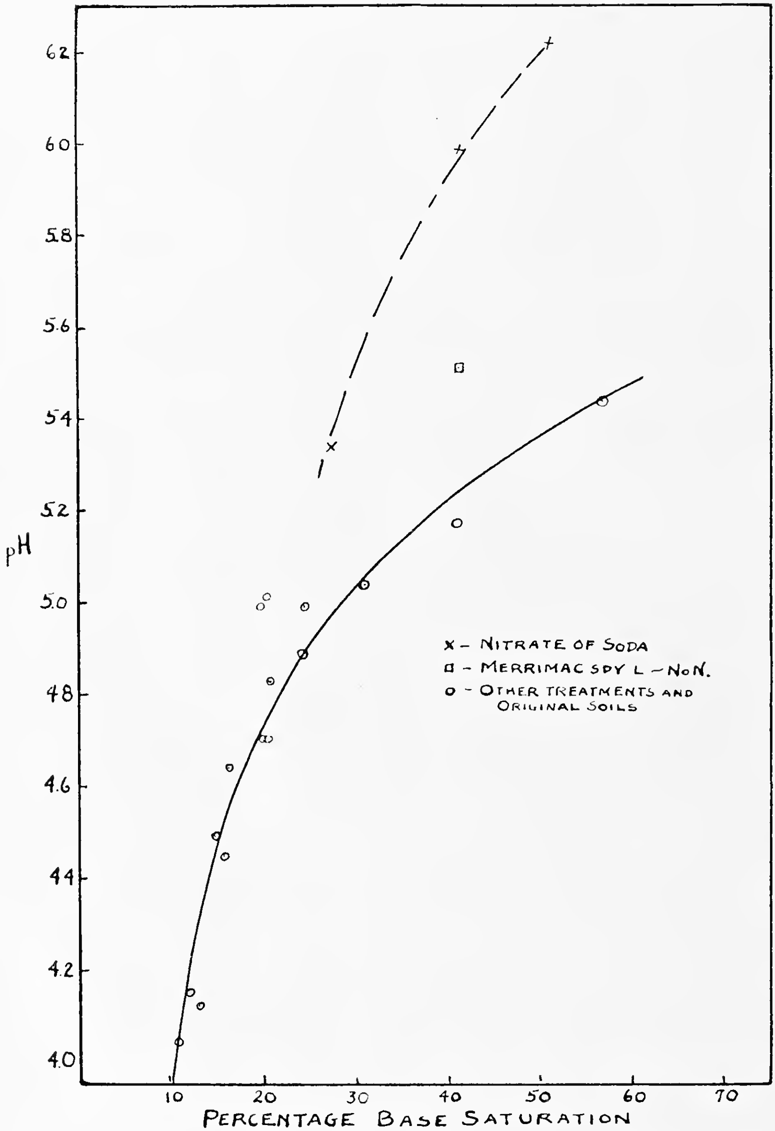

FIGURE 126. Relationship between pH and base saturation, soils from lysimeter tanks, Series A, at end of five-year period in original state.

ment are higher than on any other, as well as on the original soil. It is possible that the strong acidity of the soil solution resulting from this treatment has caused a sufficient decomposition of the soil minerals to produce end products with base exchange capacity.

Correlations between final degree of base saturation and pH are shown in Table 13 and graphically in Figure 126. The agreement is excellent on all soils and treatments, except those from the nitrate of soda tanks and the "no nitrogen" Merrimac sandy loam.

The explanation for the above discrepancy may lie in the higher percentage of exchangeable monovalent cations in the soils showing abnormally high pH in relation to base exchange capacity. This is clearly shown in the last column of Table 14. This table also shows no definite correlation between the percentage of exchangeable bases which are monovalent cations and the treatments. It is of interest to note that there has been a relative increase in monovalent cations, except on the highly pervious Merrimac loamy sand soil, in comparison with the original soils.

In the above connection the percentage of monovalent cations in relation to total base exchange capacity has been definitely reflected in

TABLE 14. MONOVALENT CATIONS IN RELATION TO TOTAL EXCHANGEABLE BASES AND BASE EXCHANGE CAPACITY — WINDSOR LYSIMETER SOILS, SERIES A

	Percentage of Exchangeable bases			Percentage of base Exchange capacity		
	Potassium	Sodium	Sum of Potassium and Sodium	Potassium	Sodium	Sum of Potassium and Sodium
Enfield v.f.s.l.						
Sodium nitrate	35.5	9.8	45.3	9.7	2.7	12.4
Ammonium sulfate	41.2	4.2	45.4	4.2	.4	4.6
Urea	42.4	2.4	44.8	6.6	.4	7.0
Cottonseed meal	41.6	3.1	44.7	6.1	.4	6.5
Original soil	25.9	3.9	29.8	5.4	.8	6.2
Merrimac l. s.						
Sodium nitrate	24.7	8.6	33.3	10.1	3.5	13.6
Ammonium sulfate	22.1	4.6	26.7	3.5	.7	4.2
Urea	25.0	3.1	28.1	5.0	.6	5.6
Cottonseed meal	19.5	3.5	23.0	3.8	.7	4.5
Original soil	25.2	8.7	33.9	6.1	2.1	8.2
Wethersfield l.						
Sodium nitrate	22.7	11.7	34.4	11.5	6.0	17.5
Ammonium sulfate	37.1	2.8	39.9	4.6	.3	4.9
Urea	34.7	1.7	36.4	8.4	.4	8.8
Cottonseed meal	28.5	1.3	29.8	8.8	.4	9.2
Original soil	6.5	4.2	10.7	3.7	2.4	6.1
Merrimac s. l.						
Sodium nitrate	29.2	9.4	38.6	11.2	3.6	14.8
Ammonium sulfate	27.4	6.9	34.3	3.6	.9	4.5
Urea	33.2	4.4	37.6	6.8	.9	7.7
Cottonseed meal	32.5	3.3	35.8	6.7	.7	7.4
No nitrogen	29.8	1.5	31.3	11.7	.6	12.3
Original soil	17.9	3.4	21.3	7.6	1.4	9.0

the turbidity of the leachates during the later years of the experiment. Leachings from the nitrate of soda treatments on the Merrimac sandy loam and Wethersfield loam soils have been decidedly turbid, especially during the second periods of the last two years, when the salt concentration was insufficient to cause at least partial flocculation within the soil. The Merrimac loamy sand, nitrate of soda treatment, gave moderately cloudy leachates, while the same treatment on the Enfield caused only a slight turbidity. The "no nitrogen" Merrimac sandy loam was also definitely turbid. The sulfate of ammonia treatments on all soils have given very clear leachates. Usually there has been a faint "milkiness" from both of the other treatments.

Measurements of the amount of colloidal material in the leachate which could be flocculated by potassium chloride were made for the leachates from the Merrimac sandy loam tanks during the second period of the fourth year (1932-1933). Results, in relation to exchangeable monovalent cations, are shown in Table 15.

Table 15. Colloidal Material in the Leachates from Merrimac Sandy Loam during the Second Half of the Fourth Lysimeter Year, in Relation to Exchangeable Monovalent Cations.—Windsor Lysimeters, Series A

Treatment	Colloidal Material in p.p.m.	Monovalent Cations in Percentage of Base Exchange Capacity
Sodium nitrate	193.5	14.8
Ammonium sulfate	4.1	4.5
Urea	50.0	7.7
Cottonseed meal	22.5	7.4
No nitrogen	69.0	12.3

Exchangeable ammonia. The soil samples used in this study were all taken in the spring prior to fertilization. Preliminary soil tests showed less than four parts per million of ammonia nitrogen in all cases, or the equivalent of less than .03 milli-equivalent per 100 gm. of soil. Failure to include exact data on this constituent in the sum of the exchangeable bases thus introduces no significant error.

Relationships between Leaching Losses and the Exchangeable Bases

Table 11 has shown clearly that marked changes in exchangeable amounts of the various bases in the soils have taken place during the periods of treatment in the lysimeters. Quantities lost by leaching, in excess or deficiency of amounts added in the fertilizer treatment and precipitation, should show the extent to which the soil has been enriched or depleted. A comparison of this net gain or loss with the change in exchangeable bases thus gives a measure of the extent to which non-exchangeable forms of the constituent have been affected. If the net loss from the soil by leaching exceeds the loss in the exchangeable form, it is reasonable to assume that the difference has been made up by the solubility of non-exchangeable materials. On the other hand, if the change in an exchangeable base shows a greater depletion or smaller

accumulation than would be expected from the net change due to leaching, it is presumptive evidence that a portion of the amount added in the treatment has not remained in the soil in a sufficiently active form to replenish losses from the base exchange complex. In other words, in the latter case, the constituent has been fixed in a non-exchangeable form, to the extent of the difference thus calculated.

Calcium is thus presented in Table 16. In most cases there has been a net loss in calcium as a result of leaching. In all cases nitrate of soda treatments have resulted in slight fixation in the non-exchangeable forms, to a maximum degree on the Wethersfield loam. Sulfate of ammonia has consistently shown greater loss by leaching than indicated by the depletion in the non-exchangeable calcium. This was also true of cottonseed meal, to a greater degree than sulfate of ammonia on the two most base-deficient soils (Enfield v.f.s.l. and Merrimac loamy sand). Urea has also resulted in calcium depletion from non-exchangeable sources, with the exception of the Merrimac loamy sand soil. The "no nitrogen" Merrimac sandy loam has shown a net loss by leaching almost identical to the depletion in exchangeable calcium, indicating that the nitrogen treatment is the chief factor in the net effects upon non-exchangeable calcium.

Table 16. Changes in Exchangeable Calcium in Comparison with Net Changes Resulting from Additions and Leachings
Windsor Lysimeter Soils 1929-1934
(In milli-equivalents per 100 gm. of soil)

	Change in exchangeable form	Net change from additions and leachings	Non-exchangeable form, fixed (+) or liberated (—)
Enfield v.f.s.l.			
Sodium Nitrate	.118—	.041+	.159+
Ammonium Sulfate	.552—	.662—	.110—
Urea	.415—	.553—	.028—
Cottonseed meal	.474—	.866—	.392—
Merrimac l. s.			
Sodium Nitrate	.244+	.366+	.112+
Ammonium Sulfate	.077—	.173—	.096—
Urea	.005—	.044+	.049+
Cottonseed meal	.024—	.339—	.315—
Wethersfield l.			
Sodium Nitrate	1.338—	1.015—	.323+
Ammonium Sulfate	2.985—	3.506—	.521—
Urea	2.424—	2.795—	.371—
Cottonseed meal	2.155—	2.504—	.349—
Merrimac s. l.			
Sodium Nitrate	.492—	.471—	.021+
Ammonium Sulfate	1.098—	1.955—	.857—
Urea	.894—	1.386—	.493—
Cottonseed meal	.923—	1.549—	.626—
No nitrogen	.234—	.230—	.004+

Nitrate of soda has produced little acidity in the soil solution, if the reaction of the leachate is a criterion. This treatment has supplied the maximum concentration of soluble cations. Under such conditions some of the calcium appearing in the leachate has been withdrawn from the base exchange complex, with a lessened solubility of the calcium applied in the fertilizer in the form of calcium phosphates. Some of the exchangeable calcium liberated also combines with the dicalcium phosphate applied as "precipitated bone" to form tricalcium phosphates.

Sulfate of ammonia, through its development of a highly acid soil solution, has depleted exchangeable calcium to a very low value. It has removed all of the calcium applied as precipitated bone, and has dissolved some calcium from non-exchangeable materials in the soil, especially on the initially less base-depleted Wethersfield loam and Merrimac sandy loam.

Urea has shown the same tendencies as sulfate of ammonia, to a lesser degree, except on the Merrimac loamy sand. On this calcium-poor soil, some of the calcium from the treatment has not been leached, and has probably remained in the soil as the phosphate.

TABLE 17. CHANGES IN EXCHANGEABLE MAGNESIUM IN COMPARISON WITH NET CHANGES RESULTING FROM ADDITIONS AND LEACHINGS
WINDSOR LYSIMETER SOILS 1929-1934
(In milli-equivalents per 100 gm. of soil)

	Change in exchangeable form	Net change from additions and leachings	Non-exchangeable form. fixed (+) or liberated (—)
Enfield v.f.s.l.			
Sodium Nitrate	.126+	.103+	.023—
Ammonium Sulfate	.074—	.084—	.020—
Urea	.013—	.037—	.024—
Cottonseed meal	.021+	.160—	.181—
Merrimac l. s.			
Sodium Nitrate	.122+	.210+	.088+
Ammonium Sulfate	.044—	.010—	.034+
Urea	.037—	.092+	.129+
Cottonseed meal	.012—	.004+	.016+
Wethersfield l.			
Sodium Nitrate	.001+	.094+	.093+
Ammonium Sulfate	.430—	.512—	.082—
Urea	.350—	.232—	.118+
Cottonseed meal	.184—	.124—	.024+
Merrimac s. l.			
Sodium Nitrate	.019—	.101+	.120+
Ammonium Sulfate	.154—	.341—	.187—
Urea	.161—	.119—	.042+
Cottonseed meal	.114—	.138—	.024—
No nitrogen	.023+	.191+	.168+

Cottonseed meal has consistently caused leaching of more calcium than applied. It is to be noted that this treatment, supplying most of its phosphorus in organic form, added much less calcium than the other applications. In this case the depletion in exchangeable calcium was definitely much less than the excess of leaching. It is probable that the decomposition of this organic material has had a definite solvent effect on non-exchangeable minerals containing calcium.

Magnesium is thus presented in Table 17. The net change from additions and leachings has been in harmony with the change in exchangeable magnesium, and is in general of the same approximate magnitude. The small differences, indicating apparent fixation or liberation from non-exchangeable material, are not consistent with treatment, and are probably not significant.

Potassium is thus presented in Table 18. In this case the amount added to the soil has been in excess of leaching in all cases. On the other hand, there has been depletion in exchangeable potassium on all soils except the Wethersfield loam (of highest base exchange capacity) for one or more treatments, especially sulfate of ammonia.

Table 18. Changes in Exchangeable Potassium in Comparison with Net Changes Resulting from Additions and Leachings
Windsor Lysimeter Soils, 1929-1934
(In milli-equivalents per 100 gm. of soil)

	Change in exchangeable form	Net change from additions and leachings	Non-exchangeable form, fixed (+) or liberated (—)
Enfield v.f.s.l.			
Sodium nitrate	.291+	.708+	.417+
Ammonium sulfate	.082—	.338+	.420+
Urea	.077+	.477+	.400+
Cottonseed meal	.048+	.382+	.334+
Merrimac l. s.			
Sodium nitrate	.130+	.572+	.442+
Ammonium sulfate	.078—	.332+	.411+
Urea	.032—	.437+	.469+
Cottonseed meal	.076—	.332+	.408+
Wethersfield l.			
Sodium nitrate	.639+	1.113+	.492+
Ammonium sulfate	.087+	.507+	.420+
Urea	.395+	.880+	.492+
Cottonseed meal	.410+	.897+	.487+
Merrimac s. l.			
Sodium nitrate	.181+	.537+	.356+
Ammonium sulfate	.190—	.210+	.408+
Urea	.040—	.354+	.394+
Cottonseed meal	.048—	.260+	.308+
No nitrogen	.211+	.500+	.289+

Inspection of the third column of Table 18 shows that the non-exchangeable potassium residue in the soil is reasonably constant for all soils and treatments. The variation on all nitrogen treatments has ranged only from .308 to .492 milli-equivalents per 100 gm. of soil. These relationships between exchangeable and residual non-exchangeable potassium are also illustrated by Figure 127.

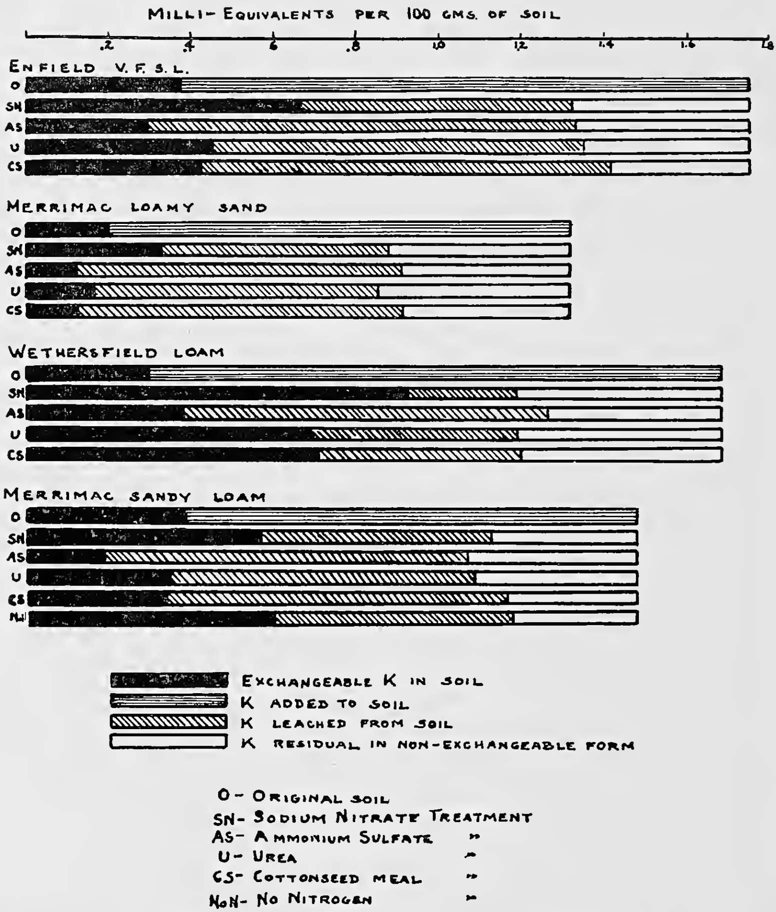

FIGURE 127. Potassium relationships in Windsor lysimeter soils, Series A, at end of five-year period and in original state.

The above data is unquestionably significant. The average difference between duplicate determinations of exchangeable potassium of samples from the same lysimeter tank has been .0015 milli-equivalent per 100 gm. of soil.The mean difference between averages of two determinations on soils from duplicate tanks was .0029 mileq. per 100 gm. of soil. The differences in quantities of potassium leached from duplicate tanks have averaged .022 mileq. and have not exceeded .069 milli-equivalent.

Depletion in exchangeable potassium in the soils from the sulfate of ammonia treatments, with the exception of the Wethersfield loam, has been verified by experiments here. The first crop of tobacco grown in greenhouse pots filled with the soils taken from the lysimeters at the conclusion of the experiment, has shown potash symptoms only in these cases.

The extent of potash fixation in non-exchangeable form, in percentages of amounts applied, is shown in Table 19. It is thus seen to range from 24.4 to 42.2 per cent of the amount applied. Thus calculated, the maximum fixation has been on the soil of least base-exchange capacity. There is nothing to indicate that the non-exchangeable fixation is at all related to the amounts of colloidal material in the soil. It is apparently unrelated to the reaction of the soil solution, since the amounts are substantially the same for nitrate of soda and sulfate of ammonia on corresponding soils.

TABLE 19. DISTRIBUTION OF POTASSIUM ADDED TO THE SOIL DURING THE FIVE-YEAR PERIOD, WINDSOR LYSIMETERS, SERIES A
(In percentages of total additions)

	Leached in excess of depletion of exchange K	Increase in exchange K	Residual in non-exchangeable form
Enfield v.f.s.l.			
Sodium nitrate	48.2	21.3	30.5
Ammonium sulfate	69.4	0	30.6
Urea	65.2	5.6	29.2
Cottonseed meal	72.1	3.5	24.4
Merrimac l. s.			
Sodium nitrate	48.9	11.6	39.5
Ammonium sulfate	62.9	0	37.1
Urea	57.8	0	42.2
Cottonseed meal	63.3	0	36.7
Wethersfield l.			
Sodium nitrate	18.7	46.0	35.3
Ammonium sulfate	63.6	6.2	30.2
Urea	36.2	28.4	35.4
Cottonseed meal	35.5	29.5	35.0
Merrimac s. l.			
Sodium nitrate	50.4	16.8	32.8
Ammonium sulfate	62.2	0	37.8
Urea	63.6	0	36.4
Cottonseed meal	71.4	0	28.6
No nitrogen	53.8	19.5	26.7

SODIUM (Table 20) has been applied in excess of the amounts leached on all nitrate of soda treatments, and the accumulation in the exchangeable form has been less than the net gain for the soil. As has been previously noted, at least a part of this discrepancy may be due to possible incomplete recovery of sodium in the laboratory determinations during the first two years. However, it is not believed that this is the case to any considerable degree, since the average data for the last three years show a similar net gain in the soil, out of proportion to exchangeable sodium recovered.

On all other treatments there has been a slight, but consistent, liberation of non-exchangeable sodium. However, it is to be recalled that the sodium additions in these cases are derived from precipitation, which is estimated for five years on the basis of the last three years' data.

TABLE 20. CHANGES IN EXCHANGEABLE SODIUM IN COMPARISON WITH NET CHANGES RESULTING FROM ADDITIONS AND LEACHINGS
WINDSOR LYSIMETER SOILS, 1929-1934
(In milli-equivalents per 100 gm. of soil)

	Change in exchangeable form	Net change from additions and leachings	Non-exchangeable form, fixed (+) or liberated (—)
Enfield v.f.s.l.			
Sodium nitrate	.129+	.984+	.855+
Ammonium sulfate	.026—	.112—	.086—
Urea	.030—	.070—	.040—
Cottonseed meal	.024—	.072—	.048—
Merrimac l. s.			
Sodium nitrate	.046+	.506+	.460+
Ammonium sulfate	.044—	.080—	.036—
Urea	.048—	.070—	.022—
Cottonseed meal	.047—	.084—	.037—
Wethersfield l.			
Sodium nitrate	.291+	.777+	.486+
Ammonium sulfate	.162—	.180—	.018—
Urea	.157—	.173—	.016—
Cottonseed meal	.158—	.177—	.019—
Merrimac s. l.			
Sodium nitrate	.110+	.619+	.509+
Ammonium sulfate	.026—	.099—	.073—
Urea	.028—	.085—	.056—
Cottonseed meal	.039—	.052—	.014—
No nitrogen	.041—	.019—	.022+

MANGANESE is similarly compared in Table 21. The soils show depletion of exchangeable manganese in all cases, but to a smaller degree than would be expected from leaching losses, except in the cases of nitrate of soda and cottonseed meal on the two less acid soils, and the "no-nitrogen" Merrimac sandy loam. This would indicate that there has been liberation of manganese from non-exchangeable sources to supply the amounts appearing in the leachates. This tendency has been most marked under the ammonium sulfate treatments. On the other hand, it would appear that the less acid conditions existing under sodium nitrate and cottonseed meal treatments and in the absence of nitrogenous fertilizers have offset this effect and have permitted some fixation in non-exchangeable form in the Wethersfield loam and Merrimac sandy loam soils.

Manganese presents a somewhat different problem from that of the other bases. In fact there is a difference of opinion among soil scientists as to the identification of this element as exchangeable in the soil. Schollenberger (43) has aptly described it as a "labile" base. It is sensitive to oxidizing or reducing conditions in the soil, and may be thus readily removed, at least temperorarily, from possible base exchange reactions.

However, a definite quantity is capable of being removed from the soil by neutral salt extraction or electro-dialysis. Hence it appears proper to assume that a portion of the base exchange capacity may be occupied by the manganese ion.

TABLE 21. CHANGES IN EXCHANGEABLE MANGANESE IN COMPARISON WITH LOSSES BY LEACHINGS — WINDSOR LYSIMETER SOILS, 1929-1934
(In milli-equivalents per 100 gm. soil)

	Change in exchangeable form	Losses by leachings	Non-exchange-able form, fixed (+) or liberated (—)
Enfield v.f.s.l.			
Sodium nitrate	.011—	.016—	.005—
Ammonium sulfate	.030—	.174—	.144—
Urea	.022—	.133—	.111—
Cottonseed meal	.007—	.061—	.056—
Merrimac l. s.			
Sodium nitrate	.003—	.014—	.011—
Ammonium sulfate	.013—	.112—	.099—
Urea	.010—	.050—	.040—
Cottonseed meal	.003—	.054—	.051—
Wethersfield l. c.			
Sodium nitrate	.053—	.001—	.052+
Ammonium sulfate	.048—	.259—	.211—
Urea	.030—	.036—	.006—
Cottonseed meal	.024—	.002—	.022+
Merrimac s. l.			
Sodium nitrate	.056—	.006—	.050+
Ammonium sulfate	.079—	.239—	.160—
Urea	.043—	.109—	.066—
Cottonseed meal	.043—	.022—	.021+
No nitrogen	.054—	.003—	.051+

ACIDITY OR ALKALINITY OF NITROGENOUS FERTILIZERS AS MEASURED BY THE LYSIMETER EXPERIMENTS

Recently wide attention has been attracted to the method of Pierre (39) for calculating the acid or alkaline tendency of a fertilizer constituent in terms of calcium carbonate equivalent. The data obtained in this investigation afford an opportunity for testing the validity of the calculated values assigned by Pierre.

Under the uncropped conditions existing in the soils of the "surface soil" lysimeters, all of the nitrogen in the fertilizer material is theoretically acid in its effect when converted into nitrates, if not already in that form. On the basis of Pierre's data, the calculated effects of the fertilizer ingredients applied, given in Table 2, are as follows for the five years of this experiment, in terms of calcium carbonate equivalent per acre:

Nitrate of soda	1368 lbs. basic
Sulfate of ammonia	5775 lbs. acid
Urea	2203 lbs. acid
Cottonseed meal	2525 lbs. acid
No nitrogen	1368 lbs. basic

The basicities of nitrate of soda and no-nitrogen treatments are accounted for by precipitated bone, carbonate of potash and carbonate of magnesia in the fertilizer applications.

The above values are based on the assumption that all of the nitrogen added in the fertilizer is nitrified and leached from the soil in combination with exchangeable bases which are not replaced, except by hydrogen. The above conditions are not entirely fulfilled in this experiment.

Nitrogen, leached in the nitrate form in excess of the amount applied, may be expected to increase the acidity of the soil to the same degree as if a similar amount of urea nitrogen had been applied and leached from the soil as nitrates. On the other hand, if added nitrogen is not recovered from the soil in the leaching, either as nitrates or ammonia, during the year following its application, it has been either synthesized into organic compounds by microbial activities, or liberated in the gaseous state. In both cases there would be no acid effects from amounts of nitrogen corresponding to the incomplete recovery. Preliminary tests for ammonia nitrogen in the soils collected in May, 1934, showed less than .05 milli-equivalents per 100 gm. of soil in all cases.

Table 22. Nitrogen Recovery in the Leachate in Relation to Amounts Applied and Corrections as to Acidity or Basicity of Fertilizer Treatments. Windsor Lysimeters, Series A, 1929-1934

	Pounds of nitrogen per acre				Corrections in calculated effect of fertilizer—in lbs. $CaCO_3$ equiv.*
	Applied in fertilizer	Leached as Nitrates	Leached as Ammonia	Total Recovery	
Enfield v.f.s.l.					
Sodium nitrate	1000	1056.4	10.7	1066.6	218 A
Ammoniun sulfate	1000	820.7	45.1	865.8	764 B
Urea	1000	855.8	11.3	867.1	495 B
Cottonseed meal	1000	621.9	5.5	627.4	1352 B
Merrimac l. s.					
Sodium nitrate	1000	1069.1	8.2	1077.3	247 A
Ammonium sulfate	1000	492.9	287.1	780.0	2822 B
Urea	1000	693.3	111.0	804.3	1065 B
Cottonseed meal	1000	533.0	18.3	551.3	1702 B
Wethersfield l.					
Sodium nitrate	1000	1102.4	5.2	1107.6	384 A
Ammonium sulfate	1000	883.0	33.9	916.9	504 B
Urea	1000	980.6	8.3	988.9	49 B
Cottonseed meal	1000	666.1	4.1	670.2	1191 B
Merrimac s. l.					
Sodium nitrate	1000	1164.1	6.4	1170.5	586 A
Ammonium sulfate	1000	812.5	127.4	939.9	1106 B
Urea	1000	903.3	25.8	929.1	345 B
Cottonseed meal	1000	722.7	7.1	729.8	991 B
No nitrogen	—	298.1	6.8	304.9	1064 A

*Amounts added in precipitation disregarded in this calculation.

Ammonia nitrogen, leached from the sulfate of ammonia treatment, in effect operates as a corresponding decrease in rate of application of ammonium sulfate. In other cases ammonia nitrogen in the leachate decreases the calculated acidity of the treatment by an equivalent amount.

If the sulfates applied in the fertilizer are incompletely removed in the leachate, the treatment has been less acid by an amount corresponding to the sulfur which fails to leach from the soil.

It is thus seen that the calculated effect of the fertilizer is subject to the above corrections, before they may be properly applied in comparison with other data at hand.

Tables 22 and 23 present data as to nitrogen and sulfate recovery in the leaching, in relation to the amounts applied. Since changes in acidity or alkalinity are conveniently expressed in terms of equivalent pounds of calcium carbonate per acre, the data are thus stated in these and subsequent tables. In calculating data on the individual soils from the previously used terms of "milli-equivalents per 100 gm. of soil", the calculation is as follows:

$$\text{Equivalent lbs. per acre} = (\text{mil-equiv. per 100 gm. of soil}) \times (\text{lbs. per acre of 2 mm. soil}) \times .0005$$

TABLE 23. SULFUR RECOVERY IN THE LEACHATES IN RELATION TO AMOUNTS ADDED AND CORRECTIONS IN CALCULATED ACIDITY OF SULFATE OF AMMONIA. WINDSOR LYSIMETERS, SERIES A, 1929-1934

	Pounds of sulfur per acre			
	Entering soil in fertilizer and rainfall	Leached	Excess leached (E) or residual in soil (R)	Correction in calculated acidity of sulfate of ammonia — lbs. $CaCO_3$ equiv.
Enfield v.f.s.l.				
Sodium nitrate	289.9	456.3	166.4 (E)	
Ammonium sulfate	1434.7	1106.5	328.2 (R)	— 1025 B
Urea	289.9	319.5	29.6 (E)	
Cottonseed meal	234.2	331.6	97.4 (E)	
Merrimac l. s.				
Sodium nitrate	289.9	306.7	16.8 (E)	
Ammonium sulfate	1434.7	1239.0	195.7 (R)	— 612 B
Urea	289.9	256.7	33.2 (R)	
Cottonseed meal	234.2	230.9	3.3 (R)	
Wethersfield l.				
Sodium nitrate	289.9	331.1	41.2 (E)	
Ammonium sulfate	1434.7	1157.8	276.9 (R)	— 863 B
Urea	289.9	270.4	19.5 (R)	
Cottonseed meal	234.2	281.3	47.1 (E)	
Merrimac s. l.				
Sodium nitrate	289.9	348.0	58.1 (E)	
Ammonium sulfate	1434.7	1256.2	178.5 (R)	— 558 B
Urea	289.9	290.5	0.6 (E)	
Cottonseed meal	234.2	285.8	51.6 (E)	
No nitrogen	289.9	317.8	27.9 (E)	

To be strictly accurate, the excess of sulfates leached over amounts applied, occurring in some cases, should be taken into account as a factor in making the soil more acid than calculated from the treatment. Such an excess is probably due to sulfofication by biological process in the soil. However, it is relatively small, and is inconsistent with respect to treatment except for nitrate of soda, where the decreased acidity is favorable to the activities of sulfofying organisms.

The best criteria of the acidic or basic effect of the fertilizer are the changes produced in the exchangeable bases and exchangeable hydrogen of the soil. Previously presented data, recalculated in terms of equivalent pounds of calcium carbonate, are presented in Table 24, in comparison with theoretical values, as corrected by amounts given in Tables 22 and 23.

TABLE 24. ACIDITY OR BASICITY OF FERTILIZER TREATMENTS AS MEASURED BY CHANGES IN EXCHANGEABLE BASES AND EXCHANGEABLE HYDROGEN, IN COMPARISON WITH CORRECTED THEORETICAL VALUES
WINDSOR LYSIMETER SOILS, SERIES A
(In pounds $CaCO_3$ equivalent per acre)

	From sum of exchangeable bases	From exchangeable hydrogen	From difference between exchange hydrogen and base exchange capacity	Average	Corrected theoretical values
Enfield v.f.s.l.					
Sodium nitrate	334B*	617B	602B	518B	1150B
Ammonium sulfate	606A*	946A	898A	817A	3886A
Urea	323A	553A	634A	603A	1708A
Cottonseed meal	350A	609A	569A	509A	1173A
Merrimac l. s.					
Sodium nitrate	527B	274B	264B	355B	1121B
Ammonium sulfate	250A	372A	205A	276A	2341A
Urea	131A	59A	29B	54A	1138A
Cottonseed meal	160A	29A	10A	66A	823A
Wethersfield l.					
Sodium nitrate	371A	205A	134A	237A	984B
Ammonium sulfate	2728A	2868A	2568A	2721A	4408A
Urea	2027A	1943A	1770A	1913A	2152A
Cottonseed meal	1640A	1367A	1367A	1458A	1334A
Merrimac s. l.					
Sodium nitrate	282A	8B	51A	108A	782B
Ammonium sulfate	1579A	1304A	1523A	1469A	4111A
Urea	1185A	956A	1189A	1110A	1858A
Cottonseed meal	1185A	695A	944A	941A	1534A
No nitrogen	96A	103A	122A	107A	304B

*B—decreasing acidity; A—increasing acidity.

Results of three methods of calculation from the soils data are in substantial agreement. These are shown in Figure 128, illustrating the

great differences resulting from the same amount of material on the various soils. Table 24 indicates that they also differ widely from the theoretical values. In all cases nitrate of soda has been considerably less basic, while sulfate of ammonia has been decidedly less acid than could be computed from the formula. Urea and cottonseed meal give reasonably good agreement on the Wethersfield and Merrimac sandy loam soils, but are much less acid in their effects upon the other two soils, which were definitely base-deficient before the treatments were started.

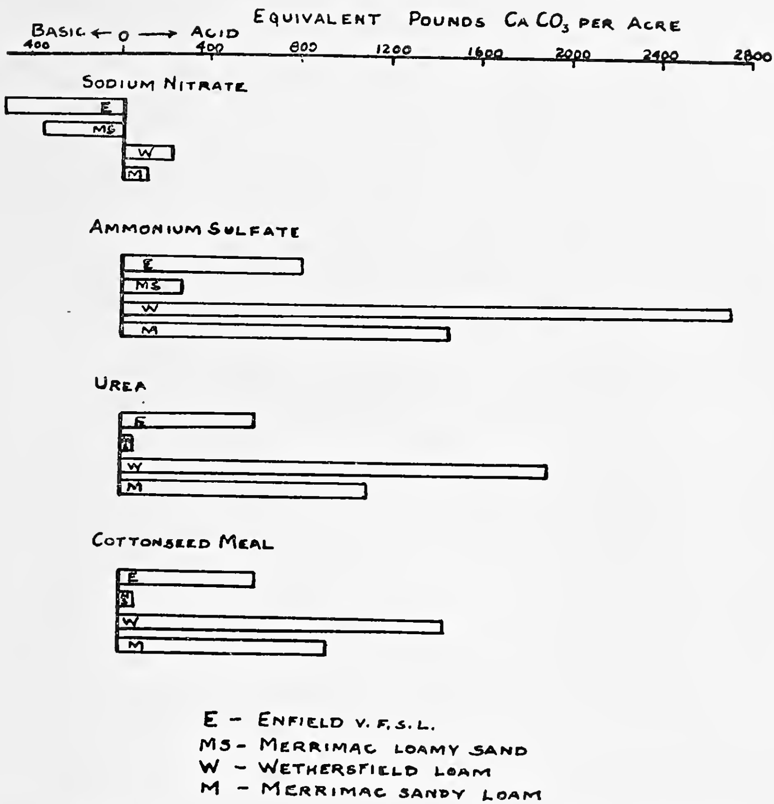

FIGURE 128. Average effects of nitrogenous fertilizers, as measured by the base status of the soil at the end of five years of annual treatment with 200 lbs. of nitrogen, Windsor lysimeter soils, Series A.

The theoretical computation of the acidity or basicity of the fertilizer disregards three other important factors that have been operative in these soils.

First, anions leached from the soil may be combined with bases liberated from non-exchangeable material in the soil. This is more especially true of calcium on the more acid treatments. Thus it was seen in Table 16 that in practically all cases sulfate of ammonia, urea, and cottonseed meal liberated more calcium into the leachate than could be computed

from amounts added to the soil and changes in exchange calcium. Manganese appearing in the leachate was much in excess of the depletion of exchangeable manganese.

Second, bases may be leached to a less degree than can be similarly computed, as a result of their fixation in the soil in non-exchangeable form. This was especially true of potassium on all treatments, and was apparently the case with calcium and sodium on nitrate of soda treatments. In the latter case, the result would be to cause the soil to become less basic than predicted from the fertilizer formula.

Third, anions may be combined with non-exchangeable bases, such as aluminum, iron or some other element which does not directly effect base exchange equilibria. Much aluminum has been leached from the soils under acidic treatments, and substantial amounts of undetermined cations must have leached, in order to balance the total anion loss.

Table 25 presents a summary of the combined operation of these three factors.

TABLE 25. SUMMARY OF BASIC AND ACIDIC EFFECTS OF FERTILIZER TREATMENTS, AS SHOWN BY SOIL CHANGES AND LYSIMETER DATA
WINDSOR LYSIMETER SOILS, SERIES A, 1929-1934

	Average base exchange effects	Other Factors I[1]	II[2]	III[3]	Total effect of treatment
Enfield v.f.s.l.					
Sodium nitrate	518B*	23A	1288B	788A	995B
Ammonium sulfate	817A*	625A	337B	3083A	4188A
Urea	603A	163A	321B	1148A	1593A
Cottonseed meal	509A	541A	268B	736A	1518A
Merrimac l. s.					
Sodium nitrate	355B	11A	1088B	614A	818B
Ammonium sulfate	276A	226A	435B	1957A	2024A
Urea	54A	61A	633B	688A	170A
Cottonseed meal	66A	365A	415B	735A	751A
Wethersfield l.					
Sodium nitrate	273A	——	1142B	58B	1437B
Ammonium sulfate	2721A	664A	332B	882A	3935A
Urea	1913A	310A	482B	2B	1739A
Cottonseed meal	1458A	291A	421B	40A	1368A
Merrimac s. l.					
Sodium nitrate	108A	——	1073B	408A	1589B
Ammonium sulfate	1469A	1296A	414B	1268A	3619A
Urea	1110A	624A	443B	210A	1501A
Cottonseed meal	941A	674A	334B	326A	1607A
No nitrogen	107A	——	542B	283A	152B

[1]I—Exchangeable bases liberated from non-exchangeable forms.
[2]II—Exchangeable bases fixed in non-exchangeable form.
[3]III—Leaching of non-exchangeable cations (Aluminum and undetermined).
*B—decreasing acidity; A—increasing acidity.

It is apparent from this table that the total effects of the fertilizer agree with theoretical values as corrected for excess or incompleteness of nitrogen and sulfur recovery in the leachate. On the two more

acid soils, the removal of non-exchangeable bases in combination with nitrates and sulfates is a more important factor than that of depletion of exchangeable bases, on all of the acid fertilizers. The basic effect of nitrate of soda, as measured by base exchange determinations, is less than the fixation of bases in non-exchangeable form on all nitrate of soda treatments.

It must be concluded that on all acid soils of low base exchange capacity, the acidity or basicity of fertilizers is only partially expressed as a direct change in the degree of acidity of the soil. On the other hand, theoretical evaluations by Pierre's calculation properly express the potential effects of the fertilizer, and on soils containing large amounts of exchangeable calcium, soil changes will be of a similar order of magnitude.

Acidity or Alkalinity of Fertilizers under Cropped Conditions

During the same period, a separate series of lysimeter tanks (Series B), containing the Merrimac sandy loam soil with subsoil to an 18-inch depth, has been under study. The same treatments as applied to the surface soil tanks, as well as 12 other nitrogenous fertilizer materials, have been used in this set of tanks. Tobacco has been grown in these each year. The plants have been cut off at ground level, removed, dried, weighed and analyzed each year, except in 1929 (the first year of the experiment), when the crop was so badly damaged by hail that it was chopped up and returned to the soil.

This above series is being continued for a longer period. Hence the leachate data will not be presented in detail.

The surface soils in these tanks were sampled at the time of removal of the surface soils from the shallow tanks. It was undesirable to remove more than one or two ounces of the soil, since larger amounts would significantly decrease the total amount remaining in tanks of only 20-inch diameter. Hence the soils data available include only determinations of pH, exchangeable hydrogen and base exchange capacity.

However, these results, in combination with data on leaching and crop removal, are sufficient for comparison with the uncropped soil of this type.

No significant amounts of aluminum appeared in the leachates from any of these soils during the five years. There was no loss of manganese in the drainage water, except in the case of the sulfate of ammonia treatment, which leached a slight amount during the last year.

A summary of the removals of the various constituents by crops and leachings, for the treatments also used in the uncropped series, is presented in Table 26. Results are computed in terms of milli-equivalents per 100 gm. of surface soil in order to provide comparative data. It is recognized, of course, that the subsoil plays a part, but this cannot be evaluated until the soil is removed from the tanks.

The analyses of the tobacco crop do not support the assumption that half of the nitrogen thus removed from the soil is in excess of base intake by the plant.* Silica was not determined, since it is difficult to distinguish between mechanical contamination of the leaves and physiological removal from the soil. The latter is likely to be less than the former in the case of tobacco.

*Analyses of plant material by Analytical Chemistry Department.

TABLE 26. LEACHING AND CROP REMOVAL FROM WINDSOR LYSIMETERS, SERIES B, 1929-1934

(In milli-equivalents per 100 gm. of surface soil)

		Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	No Nitrogen
Basic constituents:						
Potassium	—leached	.469	.933	.509	.677	.516
	in crop	.458	.278	.409	.395	.177
	total	.927	1.211	.918	1.072	.693
Sodium	—leached	2.404	.144	.116	.134	.112
	in crop	.144	.012	.022	.015	.009
	total	2.548	.156	.138	.149	.121
Calcium	—leached	.980	3.090	1.628	1.383	.914
	in crop	.375	.257	.428	.315	.138
	total	1.355	3.347	2.056	1.698	1.052
Magnesium	—leached	.229	.706	.355	.347	.270
	in crop	.184	.111	.189	.200	.075
	total	.413	.817	.544	.547	.345
Manganese	—leached	——	.028	——	——	——
	in crop	.002	.024	.012	.009	.001
	total	.002	.052	.012	.009	.001
Ammonium	—leached and total	.014	.010	.005	.004	.004
Sum of cations	—leached	4.096	4.911	2.613	2.545	1.816
	in crop	1.163	.682	1.060	.934	.400
	total	5.259	5.593	3.673	3.479	2.216
Acidic constituents:						
Nitrates	—leached	2.689	2.395	1.753	1.524	.750
	in crop*	1.314	.857	1.136	1.004	.294
	total	4.003	3.252	2.889	2.528	1.004
Sulfates	—leached	1.226	3.038	.863	.801	.877
	in crop	.057	.069	.054	.063	.061
	total	1.283	3.107	.917	.864	.938
Bicarbonates	—leached and total	.500	.276	.304	.335	.290
Chlorides	—leached and total°	.051	.058	.050	.045	.044
Phosphates	—in crop & total**	.133	.072	.099	.098	.074
Sum of anions	—leached	4.466	5.767	2.970	2.705	1.961
	in crop	1.504	.998	1.289	1.165	.429
	total	5.970	6.765	4.259	3.870	2.390
Excess of acidic constituents	—leached	.370	.856	.357	.160	.145
	in crop*	.341	.316	.229	.231	.029
	total	.711	1.172	.586	.391	.174

*All of nitrogen in crop assumed as taken up in nitrate form.
°Chlorides not determined in crop; probably insignificant with no chlorides in fertilizers.
**Phosphates in leachates in undeterminable traces.

The excess of acidic over basic constituents removed in the crop is small in proportion to the total nitrogen intake. Undoubtedly some nitrogen may be taken up as ammonia nitrogen. If half of the difference between basic and acidic constituents, when all of the nitrogen in the

crop is computed as acidic, is assumed to be taken up as ammonia nitrogen, and the other half deducted from the acidic nitrogen, an arbitrary balance is thus obtained. Table 27 gives the percentage distribution of basic and acidic equivalents in the crop, on this basis.

TABLE 27. RELATIVE AMOUNTS OF BASIC AND ACIDIC CONSTITUENTS REMOVED BY THE TOBACCO CROP—WINDSOR LYSIMETERS, 1930-1933
(Calculated on basis of equivalent weight)

	Percentages of totals of basic or acidic constituent				
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	No nitrogen
Basic constituents					
Potassium	34.34	33.10	34.83	37.64	42.70
Calcium	28.11	30.59	36.44	30.01	33.30
Magnesium	13.79	13.21	16.09	19.06	18.09
Sodium	10.79	1.43	1.87	1.43	2.17
Manganese	.15	2.86	1.02	.86	.24
Ammonium*	12.82	18.81	9.75	11.00	3.50
	100.	100.	100.	100.	100.
Acidic constituents					
Nitrates*	85.76	83.22	86.97	84.66	67.44
Phosphates	9.97	8.57	8.43	9.34	17.85
Sulfates	4.27	8.21	4.60	6.00	14.71
	100.	100.	100.	100.	100.

*On basis of nitrogen assimilation distributed so as to balance basic and acidic constituents.

It is admitted that data on other crops, such as that presented by Allison (2) do not show such large amounts of bases in the ash in proportion to the nitrogen and other acidic constituents. Tobacco is essentially a "high-ash" crop, and these results are probably not applicable to typical cases of crop removal in general farming.

Soils data as to base exchange capacity, exchangeable hydrogen and pH for the surface soils of this set of tanks is given in Table 28. It is of interest to note that these data are in very good agreement with those for the uncropped surface soils of the same type, previously given in Table 12, except for the slightly greater decrease in acidity evidenced on the nitrate of soda treatment under cropped conditions.

Calculation of the acidity or basicity of the fertilizers from the soils data is complicated by the fact that if other investigations are accepted, the subsoil should show a part of the total effect of the fertilizer. Results presented should be interpreted with this factor in mind.

Table 29 shows acidity or basicity due to treatment, on the basis of the soils data, in comparison with theoretically computed values. The latter are shown both on the assumption of only 50 per cent of the nitrogen being effectively acidic during the four years of crop removal and on the basis of all the nitrogen being acidic, except that which appeared in excess of base removal by the crop. Corrections due to excess or incompleteness of nitrogen recovery (in both crop and leaching), and sulfur residual from the sulfate of ammonia treatment, are also introduced.

TABLE 28. BASE EXCHANGE AND pH DATA—WINDSOR LYSIMETERS, SERIES B. SURFACE SOIL AT END OF FIRST FIVE YEARS OF TREATMENT

	milli-equivalents per 100 gm. of soil			
	Base exchange capacity	Exchangeable hydrogen	Exchangeable bases (by difference)	pH
Sodium nitrate	5.14	2.78	2.36	6.30
	5.11	2.73	2.38	6.35
	5.13	2.76	2.37	6.33
Ammonium sulfate	5.14	4.97	.17	3.96
	5.07	4.82	.25	4.05
	5.11	4.90	.21	4.01
Urea	5.06	4.11	.95	4.85
	5.11	4.04	1.07	4.94
	5.09	4.08	1.01	4.90
Cottonseed meal	5.29	4.08	1.21	4.96
	5.29	4.14	1.15	4.97
	5.29	4.11	1.18	4.97
No Nitrogen	4.93	3.00	1.93	5.67
	4.96	2.89	2.07	5.71
	4.95	2.95	2.00	5.69
Original Soil	5.13	3.15	1.98	5.17

TABLE 29. ACIDITY OR BASICITY OF FERTILIZER TREATMENTS AS MEASURED BY CHANGE IN EXCHANGEABLE BASES AND EXCHANGEABLE HYDROGEN IN COMPARISON WITH THEORETICAL VALUES AS VARIOUSLY CORRECTED, WINDSOR LYSIMETER SOILS, SERIES B—1934

(In pounds $CaCO_3$ equivalent per acre)

	From change in exchangeable bases	From change in exchangeable hydrogen	Average	Theoretical value (50% N acid for 4 yrs.)
Nitrate of soda	376B*	355B	366B	2797B
Sulfate of ammonia	1797A*	1776A	1787A	4346A
Urea	985A	944A	965A	774A
Cottonseed meal	812A	974A	893A	1096A
No nitrogen	20B	203B	112B	1368B

	Theoretical values (50% of N acidic for 4 years) Correction I	Theoretical values—100% N acidic Correction II	Theoretical values—100% N acidic Correction I & II
Nitrate of soda	2307B	878B	1224B
Sulfate of ammonia	2721A	3674A	3755A
Urea	73A	1562A	1330A
Cottonseed meal	89A	1518A	1284A
No nitrogen	309B	309B	338B

Correction I — for excess or incompleteness of Nitrogen recovery and for residual sulfur.
Correction II — for excess of acidic constituents in the crop removed.

*B — decreasing acidity; A — increasing acidity.

The assumption that only 50 per cent of the nitrogen in the crop is basic in effect, when correction I is applied, gives a much higher basicity for nitrate of soda, and a much lower acidity for both urea and cottonseed meal, than were actually in the surface soil alone. On the other hand, the assumption that all of the nitrogen is acidic except that which actually appeared in excess of base removal by the crop (Correction II) gives results in reasonably good agreement with the soils data, with the exception of sulfate of ammonia, which is probably most effective in increasing the undetermined subsoil acidity.

The leachate data should show the total effect upon the entire soil column. Differences between bases applied and removed by drainage and crop present this picture, especially when the undetermined cations necessary to produce equilibrium with the anions in the leachate are added. This is shown in Table 30. The calculated effect that can be computed from the fertilizer formula, assuming that all of the nitrogen is acid-forming, and with the various corrections applied, is in very close agreement with data on base removal by crop and leaching, especially when the "undetermined cations" are taken into consideration.

The material presented in this section shows with a reasonable degree of conclusiveness that at least for the tobacco crop the potential acid effects of fertilizer nitrogen are considerably more than 50 per cent of the amount applied. However, on acid soils of moderately low base exchange capacity, such as are typical of the Connecticut Valley, the effects on the actual acidity of the surface soil are materially less than can be computed from an assumption that all of the nitrogen is acidic, under both cropped and uncropped conditions.

Table 30. Total Potential Acidity or Basicity of Fertilizer Treatments on the Basis of Drainage and Crop Removal Data
Windsor Lysimeters, Series B, 1929-1934
(In pounds $CaCO_3$ equivalent per acre)

	From difference between bases added and removed by leaching and crop	From difference between bases added and removed, including undetermined cations in leachate
Sodium nitrate	972B	597B
Ammonium sulfate	2959A	3828A
Urea	1010A	1372A
Cottonseed meal	1489A	1651A
No Nitrogen	469B	322B

Studies in Progress. The cropped 20-inch lysimeters (Series B) discussed in the previous section are being continued.

In May, 1934, after removing the soils from the surface soil tanks, an experiment was initiated to throw additional light upon the problem of amounts of lime required to correct for the acidity of acid nitrogenous fertilizers. The plan is briefly as follows: Two soils, apparently iden-

tical, from field plots only a few rods apart, are being studied. One of these had not been limed and is strongly acid. The other was limed twice, with dolomitic hydrated lime, during the previous five-year period, to a present reaction of about 6.0 pH. Each of these soils is treated with sulfate of ammonia, urea, and cottonseed meal, both with and without limestone equivalent to the theoretical acidity of the fertilizer. Nitrate of soda, as well as sulfate of ammonia used with other constituents having no theoretical basicity, is also included in the treatments on both soils. This experiment will be conducted along similar lines as followed in the studies herein reported.

GENERAL DISCUSSION AND CONCLUSIONS

The effects of the four nitrogenous fertilizers studied in this investigation, with respect to ion equilibria in the drainage waters and soils, may now be presented in turn.

Nitrate of soda. This material has caused a minimum of removal of bases other than sodium through leaching. This is largely due to the fact that the sodium is very weakly absorbed by the base exchange complex, thus permitting most of the nitrates to leach from the soil in the same form as applied.

The amount of sodium retained in the exchangeable form has been in proportion to base exchange capacity of the soil, for the four soils studied. This treatment has also permitted the accumulation of approximately twice as much potassium as of sodium, although the amount of potassium added in the treatment was less than one-third that of sodium, on an equivalent basis.

The sodium added has not been fully accounted for in leaching and the increase in the exchangeable sodium of the soil. Fixation of some sodium in non-exchangeable combinations is possible, but some question of the accuracy of the sodium analyses of the leachings during the first two years of the experiment precludes the possibility of convincing proof in this respect.

There has been depletion of some exchangeable calcium, except from the Merrimac loamy sand, which was already very deficient in this respect. However, in all cases less calcium has been leached than could be calculated from amounts added to the soil and changes in the exchangeable form.

A minimum of aluminum and manganese and a maximum of bicarbonates have been found in the drainage water from this treatment. The reaction of the leachings has been consistently between 6.5 and 7.4 pH. These results are in harmony with the slight theoretical basicity of the total application in which nitrate of soda is the source of nitrogen.

Increased pH has resulted on all four soils. However, as compared with the original soils, there has not been a consistent increase in degree of saturation following this treatment. It is believed that the increase in pH is due chiefly to increased percentage of monovalent cations in relation to total base exchange capacity.

As measured by base exchange trends, the nitrate of soda treatment has not shown as great a degree of alkaline effects as could be calculated

on a theoretical basis. This discrepancy is believed to be largely due to the retention of the added bases in non-exchangeable form.

Larger amounts of sulfur have appeared in the drainage water than were added in rainfall and fertilizer treatment. More sulfur appeared in the nitrate of soda leachate than from either urea or cottonseed meal. This is probably due to increased sulfofication resulting at the higher pH.

Under cropped conditions, nitrate of soda has shown a slightly greater tendency toward alkalinity in the surface soil than when the soil remained fallow. However, this was much less than the theoretical basicity on Pierre's assumption that only one-half of the nitrogen taken up by the crop was combined with an equivalent amount of bases.

There has been a definite trend toward deflocculation resulting from this treatment, which has been exhibited to the highest degree on soils showing largest final degrees of saturation with monovalent cations.

From the above results, it is obvious that nitrate of soda has no definite acid effects. It produces less drastic soil changes than the other three nitrogenous fertilizers studied. However, in comparison with a no-nitrogen treatment on one of the soils, it has resulted in a larger depletion of calcium and magnesium. The apparent basicity resulting from the nitrate of soda treatment under uncropped conditions, exhibited by increased pH, is probably not so beneficial in improving the general conditions of the soil as a similar increase in pH brought about by increased calcium saturation.

If nitrate of soda is to be regarded as a basic fertilizer, it must be on the basis of truly physiologic effects.

Sulfate of ammonia. This material has produced a maximum removal of bases from the soil. Exchangeable amounts of all bases have been brought to a very low level by five years of treatment. In fact, the two soils with the higher initial content of exchangeable bases have been made almost as low in base-saturation as the two soils which were initially quite acid.

This treatment has resulted in significantly greater amounts of removal of calcium from the soil than could be accounted for by the sum of calcium additions and losses in exchangeable calcium. It is believed that non-exchangeable sources of calcium in the soil have been made soluble and subject to leaching.

Large concentrations of aluminum and manganese appear in the leachates. The reaction of the drainage water has been consistently strongly acid (4.0 — 4.6 pH) on all four soils during the later years of the experiment. A minimum of bicarbonates is inevitable under this condition.

As measured by change in exchangeable bases in the soil, sulfate of ammonia has been much less acid than could be computed on a theoretical basis. This discrepancy has been due to a combination of two factors, liberation of bases from non-exchangeable material and leaching of aluminum and other undetermined and presumably non-exchangeable bases.

The greater proportion of the nitrogen in sulfate of ammonia has been nitrified and leached in the nitrate form on all soils, despite the strong acidity resulting from this treatment. Important amounts of ammonia nitrogen have been leached in inverse relation to the water-retentiveness of the soils. However, there has been incomplete recovery of applied

nitrogen in the leachings in all cases. Some of the sulfur applied in the treatment has also failed to appear in the drainage water.

The above results are in harmony with the well-known acid effects of this material. The net effect of the treatment upon the degree of acidity, in relation to the initial content of the exchangeable bases, is brought forth more clearly than heretofore. Soils already base-deficient are much less drastically altered by sulfate of ammonia than is the case with soils initially containing a fair content of exchangeable bases.

Marked depletion of exchangeable magnesium has resulted. This observation is important in its practical bearing upon the recent occurrences of magnesium deficiency on many crops which have been fertilized liberally with complete fertilizers, containing most of their nitrogen as sulfate of ammonia.

Urea. This material has produced depletion of soil bases, to a somewhat smaller degree than in the case of sulfate of ammonia. This is shown both by leachate data and soil studies.

The effect resulting from urea was somewhat more consistent with its calculated theoretical acidity than was the case with sulfate of ammonia. This may be due to the more complete nitrification and the smaller amount of ammonia nitrogen appearing in the leachate than for the latter material.

Urea has also produced materially increased outgo of aluminum and manganese, and decreased bicarbonate concentrations in the leachate. This was consistent with the pH. In harmony with the data on depletion of the stable exchangeable bases, the acid tendency in these respects has been much less than that of sulfate of ammonia.

Cottonseed meal. The effects of this material are somewhat more difficult to interpret than for the other nitrogenous fertilizers. Since much less calcium was applied in this treatment, there is a greater possibility of depletion of this base. In all cases much more calcium was leached than the amount applied. On the other hand, the decrease in exchangeable calcium resulting from this treatment has not been nearly so great as would be expected from net calcium losses by leaching. Much of the calcium required for combination with nitrates resulting from the biological decomposition of cottonseed meal has apparently been liberated from non-exchangeable sources.

In spite of a lessened quantity of anion leaching (chiefly nitrates) with cottonseed meal as compared with urea, the former material has caused the leaching of more potassium and magnesium on three of the four soils. This difference is probably due in part, at least, to the much smaller liberation of manganese and aluminum by cottonseed meal.

Although the acidity of the leachate has been consistently less when this material was the source of nitrogen, the degree of depletion of exchangeable bases and depression of pH at the end of the year following treatment have been substantially the same for both urea and cottonseed meal, on all four soils.

Cottonseed meal has been nitrified to a much smaller degree than urea, on the basis of the leachate data. It has not resulted in sufficient accumulations of ammonia nitrogen to permit much leaching in this form, even on the very "leachy" Merrimac loamy sand.

A part of the nitrogen applied as cottonseed meal that failed to leach, has been accumulated as residual nitrogen. However, the increase in the nitrogen content of the soil during the five years has failed to account for the greater portion of this discrepancy. This is evident from Appendix Table XIV.

SUMMARY

A comparative study has been made between four types of nitrogenous fertilizers, with respect to soil changes as evidenced by drainage losses in chemical soil analyses. The materials investigated have been nitrate of soda, sulfate of ammonia, urea and cottonseed meal. These have been used on a series of four soils of varying texture, base exchange capacity and degree of base saturation, as follows:

Enfield very fine sandy loam—base exchange capacity, 6.91 milli-equivalents per 100 gm. of soil; 21.6 per cent base saturated.
Merrimac loamy sand—base exchange capacity, 3.24 milli-equivalents per 100 gm. of soil; 29.0 per cent base saturated.
Wethersfield loam—base exchange capacity, 7.95 milli-equivalents per 100 gm. of soil; 55.6 per cent base saturated.
Merrimac sandy loam—base exchange capacity, 5.13 milli-equivalents per gm. of soil; 38.6 per cent base saturated.

The soils were in exterior lysimeters, under natural climatic conditions, for five years (May, 1929 to May, 1934). The tanks were cylindrical, 20 inches in diameter, and contained a layer of seven inches of surface soil, over a conical drainage bed of coarse quartz sand. Drainage water was collected after each period of leaching, and composites were analyzed at semi-annual periods.

The treatments supplied 200 lbs. of nitrogen, and other materials furnishing a total of 100 lbs. of phosphoric acid (P_2O_5) and 200 lbs. of potash (K_2O), per acre per year. The fertilizer was applied on May 26 of each year. These rates of application are in common use in cigar-wrapper tobacco in the Connecticut Valley district of Connecticut. The soils in the surface soil tanks were kept under fallow conditions. At the same time a separate series of deeper tanks (20 inches in depth) of the Merrimac sandy loam soil, receiving the same treatments, was cropped to tobacco each year.

The four soils have shown marked variations in amounts of drainage water, especially during the summer-fall period. The Merrimac loamy sand was the most leachy in performance. The Merrimac sandy loam soil retained practically the same proportion of the rainfall as the much heavier Wethersfield loam. The Enfield very fine sandy loam was definitely more resistant to leaching than the other three soils. For the five years, the summer-fall leachings were 30.5 per cent of the rainfall, while those from the winter-spring period were 51.2 per cent of precipitation, as an average of the four soils. These results were obtained with an average annual rainfall of 35.96 inches, which was 8.11 inches below the 62-year average.

Leachate analyses included the following determinations: Basic constituents—calcium, magnesium, potassium, sodium, ammonia nitrogen, manganese and aluminum; acidic constituents—nitrate nitrogen, sulfates, bicarbonates, chlorides, and phosphates. The hydrogen-ion concentrations of the leachates were also measured. For the purpose

of comparative study in relation to soil changes, results were computed to the basis of milli-equivalents per 100 gm. of 2 mm. soil contained in the tanks of each soil type.

A comparative summation of determined basic and acidic constituents showed an excess of anions on all soils and treatments except the nitrate of soda and urea treatments on the Wethersfield loam soil. This trend has been consistent in practically every period of analysis. The excess of acidic constituents over determined bases has been highest on sulfate of ammonia tanks and has also shown a correlation in magnitude with the initial degrees of base-unsaturation of the various soils. The source of this discrepancy is not definitely established. It may be due in part to iron for the sulfate of ammonia treatments, but this explanation is inconsistent with the uniformly smaller predominance of anions for urea, as compared with cottonseed meal.

Calcium has been leached to much greater degree during the first six months following the fertilizer application, than during the remainder of the year, although the total volume of leachate has been nearly twice as great in the second period. Potassium has leached at a much greater relative ratio to calcium during the winter and spring months, when the nitrate concentrations are low. This is a reasonable result, in view of the much greater relative solubility of calcium nitrate as compared with the sulfate or bicarbonate, a difference which is not marked in case of the corresponding potassium compounds.

In the above connection, except as affected by nitrate of soda treatments, leachings are similarly higher in proportion to calcium during the second half of the year. Magnesium retains about the same relationship to calcium during both periods.

Calcium losses from the soil have become progressively smaller from year to year. On the other hand, amounts of potassium appearing in the leachate showed an annual increase, except in the final year. The former trend is believed to be largely due to progressive depletion of the readily active forms of calcium, and may be in part affected by base replacement resulting from potassium additions in the treatment. There is evidence of a reciprocal relationship between calcium and potassium with respect to their liberation in soluble form.

Although magnesium was applied at a higher rate during the last three years, it did not show a consistent subsequent increase in the leachates. There is a possibility that the potassium has repressed the magnesium losses to a compensating degree.

Calcium losses by leaching have exceeded amounts applied, except in the following cases: Enfield v.f.s.l.—nitrate of soda; Merrimac loamy sand—nitrate of soda and urea. The excess of leaching over amounts applied has been in proportion to the initial exchangeable calcium content of the soil for corresponding treatments. The net losses have been greatest on sulfate of ammonia, and least on nitrate of soda treatments. However, on the one soil (Merrimac sandy loam) with a no-nitrogen check treatment, nitrate of soda caused a greater calcium loss than where no nitrogen was applied.

Changes in exchangeable calcium have shown a smaller loss in this respect than the net loss due to leaching, except on nitrate of soda treatments. This apparent liberation of non-exchangeable calcium was at

a maximum in the sulfate of ammonia tanks, and was higher for cottonseed meal than for urea on three of the four soils.

Exchangeable calcium was depleted to a very low quantity by the sulfate of ammonia treatment, even on the initially calcium-rich Wethersfield loam. Urea and cottonseed meal resulted in substantially the same depletion in exchangeable calcium, although the latter material supplied less calcium in the treatment. Nitrate of soda permitted loss in this respect on three of the four soils, the exception being the initially calcium-poor Merrimac loamy sand.

Net magnesium losses occurred on all treatments except nitrate of soda and no nitrogen. The changes anticipated from differences between amounts added and leached were consistent with changes in exchangeable magnesium. Losses in exchangeable magnesium were strikingly in evidence in soils from all sulfate of ammonia tanks. They were definitely greater on urea than on cottonseed meal treatments.

Less potassium was leached than was applied, in all cases. On the other hand, exchangeable potassium was depleted by sulfate of ammonia on three of the four soils, the exception being the Wethersfield loam, of highest base exchange capacity. Decreases of a smaller magnitude occurred on both of the Merrimac soils. Residues of exchangeable potassium under the nitrate of soda treatments have been in proportion to base exchange capacities of the soils.

In a comparison of changes in exchangeable potassium with net changes from additions and leachings, the latter exceeded the former, in the direction of potassium accumulation in the soil, by substantially 0.4 milliequivalents per 100 gm. of soil on all soils and treatments. This is definite evidence of potassium fixation in non-exchangeable form, independent of both soil and treatment.

Sodium, applied in large amounts in the nitrate of soda treatment, has been readily leached from the soil. It has accumulated to a small degree as exchangeable sodium in all of the soils, in proportion to their base exchange capacities. Some of the sodium applied has failed to appear either in the leaching or in the exchangeable form, indicating a possibility of non-exchangeable fixation. Sodium has been depleted by leaching to a greater degree than indicated by decreases in exchangeable sodium, on all other treatments.

Manganese has been leached to a considerable extent under all sulfate of ammonia treatments, and to a lesser extent with urea and cottonseed meal, in the order stated. It is notable than the acid nitrogenous materials caused very little manganese to leach from the Wethersfield loam soil during the first two years, although during the last two years the loss exceeded that from the very acid Enfield soil under the same treatment.

The leachings of manganese have greatly exceeded the decreases in exchangeable manganese, for both sulfate of ammonia and urea tanks.

Aluminum has been an important constituent in the leachings, in almost direct proportion to pH depression resulting from the treatments. In fact, aluminum was present in a higher equivalent proportion than was calcium, in the leachings from the sulfate of ammonia tanks of both the Enfield v.f.s.l. and Merrimac loamy sand soils, during the last year of the experiment.

Ammonia nitrogen has been leached to a significant degree from the sulfate of ammonia tanks, in all cases when leaching occurred during the early summer period. Ammonia leachings were in inverse proportion to the base exchange capacity of the soil. Some ammonia nitrogen also leached from the urea treatments and to a lesser degree, from cottonseed meal. Losses in this form from nitrate of soda tanks were insignificant.

Nitrate nitrogen losses from nitrate of soda treatments exceeded amounts applied. In all other cases there was only partial recovery of nitrogen, on the basis of the sum of nitrate and ammonia nitrogen. Urea has nitrified to a greater extent than has sulfate of ammonia, while cottonseed meal has been very incompletely recovered.

Sulfates, applied in large quantities in the sulfate of ammonia treatment, have been leached readily, but have not been fully removed during the five-year period. There has been increased sulfate outgo from the nitrate of soda tanks, indicating greater biological oxidation at this higher resultant pH.

Bicarbonate concentration in the drainage water at the time of analysis has been in inverse relationship to the degree of acidity resulting from the treatment. It is comparatively low in all cases, since none of these soils is calcareous in nature.

Chlorides appearing in the leachate have been of the same magnitude as those supplied by the precipitation, since only small traces were present in any of the materials used in the fertilizer.

The losses of phosphorus by leaching have been negligible in proportion to the amounts applied. They were at a maximum on the Merrimac sandy loam soil, especially on the nitrate of soda treatment.

The nitrogenous materials used in this study have had markedly different effects upon the amounts of exchangeable bases on the various soils. This is best evidenced by the fact that the same application of sulfate of ammonia has produced the following depletion of exchangeable bases:

Wethersfield loam	3.49	milli-equivalents	per	100	gm.	
Merrimac sandy loam	1.47	"	"	"	"	"
Enfield v.f.s.l.	0.96	"	"	"	"	"
Merrimac loamy sand	0.24	"	"	"	"	"

Soils initially high in exchangeable bases are capable of being changed by acid nitrogenous fertilizers to a much more marked degree than soils, like Enfield and Merrimac loamy sand, that are initially deficient in this respect.

When the soils attain a low base-saturation, a large proportion of the acid radicals (nitrates or sulfates) leach out in combination with aluminum, manganese and iron. A considerable portion of the calcium and magnesium leached under such conditions is apparently derived from non-exchangeable sources. The latter losses are, of course, to be regarded as potentially acidic in their final effects on the soil. Evaluations of net effects of the various fertilizers, with respect to their acidity or basicity in terms of calcium carbonate equivalent, have been computed on the basis of the various measurements. Corrections were made for excess or deficiency of nitrogen leached over amounts added, and for

ammonia nitrogen in the drainage water. Net losses or gains in total basic constituents, including aluminum, have been of the same approximate magnitude as predicted by calculation from the formula, especially when "undetermined bases" (the excess of anions over cations in the leachings) were taken into consideration.

If deductions are made for the theoretical alkalinity to be expected from the non-nitrogenous materials in the formula, the average results on the four soils indicate that under uncropped conditions: Nitrate of soda is substantially a neutral fertilizer; sulfate of ammonia is strongly acid in its effects, requiring 4.81 lbs. of calcium carbonate per pound of nitrogen in this form, to compensate for losses of bases; urea is of moderately acid tendency, requiring 2.62 lbs. of calcium carbonate per pound of nitrogen; the final effects of cottonseed meal are nearly as acid as those of urea, to the extent of 2.35 lbs. of calcium carbonate per pound of nitrogen.

Results under cropped conditions, as measured by changes in exchangeable bases and net gains or losses of bases in both crop and leachings, have indicated substantially the same total effects upon the surface soil of the Merrimac sandy loam as herein presented. The nitrate of soda treatment is apparently somewhat more alkaline when a crop is grown, but not to the extent predicted on the basis of Pierre's assumption of a 50 per cent absorption by the crop of nitrogen uncombined with an equivalent amount of bases. Tobacco, a "high ash" crop, is a possible exception to such an approximation.

More exhaustive lysimeter studies designed to measure the effects of the acid nitrogenous materials used in conjunction with equivalent amounts of limestone, on both strongly and slightly acid soils, are in progress.

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APPENDIX

Appendix Table I. Drainage Losses—Windsor Surface Soil Lysimeters

CALCIUM
(in pounds per acre)

Period	Enfield v.f.s.l. Sodium nitrate	Enfield v.f.s.l. Ammonium sulfate	Enfield v.f.s.l. Urea	Enfield v.f.s.l. Cottonseed meal	Merrimac l. s. Sodium nitrate	Merrimac l. s. Ammonium sulfate	Merrimac l. s. Urea	Merrimac l. s. Cottonseed meal
'29-'30								
1st per.	75.0	146.6	142.3	101.6	57.7	115.7	96.5	75.2
2nd per.	28.0	40.8	23.6	12.1	11.6	37.4	16.4	14.9
Yr.	103.0	187.4	165.9	113.7	69.3	153.1	112.9	90.1
'30-'31								
1st per.	66.5	116.4	112.4	77.4	46.7	69.5	44.5	44.1
2nd per.	19.5	39.4	25.8	23.0	5.1	7.3	5.1	5.9
Yr.	86.0	155.8	138.2	100.4	51.8	76.8	49.6	50.0
'31-'32								
1st per.	38.4	40.8	38.3	31.4	26.9	45.3	30.0	22.6
2nd per.	26.4	40.6	39.6	40.4	14.2	19.9	14.1	15.5
Yr.	64.8	81.4	77.9	71.8	41.1	65.2	44.1	38.1
'32-'33								
1st per.	45.7	77.6	78.5	54.0	30.3	79.6	70.2	27.9
2nd per.	16.6	14.5	11.9	13.2	10.6	12.2	14.5	12.8
Yr.	62.3	92.1	90.4	67.2	40.9	91.8	84.7	40.7
'33-'34								
1st per.	39.8	27.4	39.0	22.9	28.6	49.5	65.2	20.9
2nd per.	13.9	45.8	49.5	16.5	7.2	14.3	8.8	7.4
Yr.	53.7	73.2	88.5	39.4	35.8	63.8	74.0	28.3
'29-'34								
1st per.	265.4	408.8	410.5	287.3	190.5	359.6	306.4	190.7
2nd per.	104.4	181.1	150.4	105.2	48.7	91.1	58.9	56.5
Replicate A*	385.9	584.0	568.2	381.7	251.0	465.4	379.1	257.4
Replicate B*	353.6	595.7	553.7	403.4	227.3	436.1	351.4	237.0
5 yrs.	369.8	589.9	560.9	392.5	239.2	450.7	365.3	247.2

	Wethersfield l. Sodium nitrate	Wethersfield l. Ammonium sulfate	Wethersfield l. Urea	Wethersfield l. Cottonseed meal	Merrimac s. l. Sodium nitrate	Merrimac s. l. Ammonium sulfate	Merrimac s. l. Urea	Merrimac s. l. Cottonseed meal	Merrimac s. l. No nitrogen
'29-'30									
1st per.	124.9	243.0	163.1	120.8	144.6	352.4	231.0	190.5	105.6
2nd per.	37.9	98.5	75.5	63.3	3.8	23.7	15.9	13.7	17.2
Yr.	162.8	341.5	238.6	184.1	148.4	376.9	246.9	204.2	122.8
'30-'31									
1st per.	165.2	331.9	268.8	142.5	129.8	296.8	201.7	141.9	104.1
2nd per.	21.2	147.4	69.4	65.3	13.7	35.2	24.5	27.5	26.6
Yr.	186.4	479.3	338.2	207.8	143.5	332.0	235.2	169.4	130.7
'31-'32									
1st per.	92.3	208.7	166.5	119.6	89.8	145.1	129.1	98.0	52.9
2nd per.	29.8	131.5	93.0	89.5	19.9	54.5	34.6	50.1	35.9
Yr.	122.1	340.2	259.5	209.1	109.7	199.6	163.7	148.1	88.8
'32-'33									
1st per.	106.5	199.0	228.5	143.1	78.0	158.4	170.7	104.6	61.9
2nd per.	16.2	29.5	36.1	29.2	11.5	15.1	14.7	16.9	17.1
Yr.	122.7	228.5	264.6	172.3	89.5	173.5	185.4	121.5	79.0
'33-'34									
1st per.	95.0	56.5	131.2	105.0	76.3	67.0	104.7	84.9	37.2
2nd per.	15.0	46.5	35.4	28.0	6.9	29.4	19.9	15.4	18.1
Yr.	110.0	103.0	166.6	133.0	83.2	96.4	124.6	100.3	55.3
'29-'34									
1st per.	583.9	1039.1	958.1	631.0	518.5	1019.7	837.2	619.9	361.7
2nd per.	120.1	453.4	309.4	275.3	55.8	157.9	109.6	123.6	114.9
Replicate A	713.3	1508.3	1265.6	936.6	575.2	1181.9	941.9	757.5	476.3
Replicate B	694.7	1476.8	1269.5	876.1	573.3	1173.4	951.7	729.4	476.9
5 Yrs.	704.0	1492.5	1267.5	906.3	574.3	1177.6	946.8	743.5	476.6

*In this and subsequent tables I-XXIV, data for the two replicates of each treatment are 5-year totals

TABLE II. DRAINAGE LOSSES—WINDSOR SURFACE SOIL LYSIMETERS

MAGNESIUM

(in pounds per acre)

	Enfield v.f.s.l.				Merrimac l. s.			
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal
'29-'30								
1st per.	19.7	25.5	29.3	24.8	8.7	4.1	5.7	8.9
2nd per.	5.6	8.5	5.7	3.6	2.3	10.3	5.4	8.3
Yr.	25.3	34.0	35.0	28.4	11.0	14.4	11.1	17.2
'30-'31								
1st per.	14.6	24.0	17.0	20.0	9.3	18.5	11.2	17.9
2nd per.	6.3	9.5	5.2	11.8	3.3	1.2	0.6	2.7
Yr.	20.9	33.5	22.2	31.8	12.6	19.7	11.8	20.6
'31-'32								
1st per.	14.0	25.9	16.5	16.0	14.9	28.3	15.5	18.7
2nd per.	9.3	11.8	14.9	22.3	4.6	5.0	6.4	11.9
Yr.	23.3	37.7	31.4	38.3	19.5	33.3	21.9	30.6
'32-'33								
1st per.	22.9	21.9	30.2	33.7	19.0	40.3	34.4	31.9
2nd per.	1.4	0.7	1.2	1.3	0.9	1.2	1.4	0.9
Yr.	24.3	22.6	31.4	35.0	19.9	41.5	35.8	32.8
'33-'34								
1st per.	15.2	9.6	8.2	18.7	16.6	20.9	27.3	25.9
2nd per.	4.8	13.0	13.1	13.0	4.1	6.3	3.9	5.8
Yr.	20.0	22.6	21.3	31.7	20.7	27.2	31.2	31.7
'29-'34								
1st per.	86.4	106.9	101.2	113.2	68.5	112.1	94.1	103.3
2nd per.	27.4	43.5	40.1	52.0	15.2	24.0	17.7	29.6
Replicate A	113.0	145.1	141.7	168.7	84.5	129.7	119.6	129.3
Replicate B	114.7	155.8	141.0	161.6	82.8	142.4	104.1	136.4
5 Yrs.	113.8	150.4	141.3	165.2	83.7	136.1	111.8	132.9

	Wethersfield l.				Merrimac s. l.				
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	No nitrogen
'29-'30									
1st per.	12.7	14.3	12.0	14.0	22.3	47.1	32.0	30.4	16.5
2nd per.	11.6	20.0	13.7	12.4	2.3	1.8	5.0	2.3	2.8
Yr.	24.3	34.3	25.7	26.4	24.6	48.9	37.0	32.7	19.3
'30-'31									
1st per.	20.5	41.8	30.5	18.9	15.0	35.1	19.2	16.9	11.4
2nd per.	2.8	21.5	10.6	10.1	4.1	6.2	4.3	5.2	6.4
Yr.	23.3	63.3	41.1	29.0	19.1	41.3	23.5	22.1	17.8
'31-'32									
1st per.	15.4	27.4	21.5	22.4	13.1	31.8	16.4	17.8	9.4
2nd per.	8.1	20.7	14.0	15.6	3.6	10.9	8.4	13.8	6.7
Yr.	23.5	48.1	35.5	38.0	16.7	42.7	24.8	31.6	16.1
'32-'33									
1st per.	20.6	46.2	34.7	27.0	19.9	52.5	40.4	36.2	13.4
2nd per.	5.3	0.9	3.1	0.9	1.6	2.3	3.1	4.5	2.3
Yr.	25.9	47.1	37.8	27.9	21.5	54.8	43.5	40.7	15.7
'33-'34									
1st per.	14.2	21.8	28.9	27.7	23.4	25.1	28.4	33.1	11.3
2nd per.	4.5	17.8	9.5	8.7	3.4	5.3	6.0	7.7	6.4
Yr.	18.7	39.6	38.4	36.4	26.8	30.4	34.4	40.8	17.9
'29-'34									
1st per.	83.4	151.5	127.6	110.0	93.8	191.6	136.4	134.4	62.0
2nd per.	32.3	80.9	50.9	47.7	15.0	26.5	26.8	33.5	24.6
Replicate A	106.8	238.1	176.8	162.3	111.0	223.8	165.8	161.4	88.1
Replicate B	124.5	226.8	180.2	153.1	106.6	212.4	160.7	174.3	85.1
5 Yrs.	115.7	232.4	178.5	157.7	108.8	218.1	163.2	167.9	86.6

TABLE III. DRAINAGE LOSSES—WINDSOR SURFACE SOIL LYSIMETERS
POTASSIUM
(in pounds per acre)

	Enfield v.f.s.l.				Merrimac l. s.			
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal
'29-'30								
1st per.	15.7	13.8	14.7	15.0	28.6	31.3	29.7	33.2
2nd per.	35.9	50.7	36.6	40.7	21.8	31.4	19.5	29.1
Yr.	51.6	64.5	51.3	55.7	50.4	62.7	49.2	62.3
'30-'31								
1st per.	26.2	22.7	23.5	23.9	38.3	41.6	41.5	41.2
2nd per.	42.7	111.4	69.9	96.0	24.4	31.8	39.5	51.1
Yr.	68.9	134.1	93.4	119.9	62.7	73.4	81.0	92.3
'31-'32								
1st per.	63.4	97.3	75.1	94.5	75.1	110.6	89.2	101.3
2nd per.	55.1	72.3	70.6	96.3	33.1	29.1	35.0	46.5
Yr.	118.5	169.6	145.7	190.8	108.2	139.7	124.2	147.8
'32-'33								
1st per.	83.2	126.3	129.5	105.9	100.6	164.5	129.5	147.8
2nd per.	27.3	44.2	41.5	50.7	19.1	19.1	22.5	22.3
Yr.	110.5	170.5	171.0	156.6	119.7	183.6	152.0	170.1
'33-'34								
1st per.	44.1	35.9	41.9	47.7	53.8	109.2	86.9	85.8
2nd per.	21.7	70.3	55.8	47.9	19.9	28.3	31.1	39.1
Yr.	65.8	106.2	97.7	95.6	73.7	137.5	118.0	124.9
'29-'34								
1st per.	232.6	296.0	284.7	287.0	296.4	457.2	376.8	409.3
2nd per.	182.7	348.9	274.4	331.6	118.3	139.7	147.6	188.1
Replicate A	411.0	664.7	571.5	619.2	417.5	603.6	531.2	609.8
Replicate B	419.8	625.0	546.6	618.0	411.7	590.1	517.3	585.0
5 Yrs.	415.3	644.9	559.1	618.6	414.7	596.9	524.4	597.4

	Wethersfield l.				Merrimac s. l.				
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	No nitrogen
'29-'30									
1st per.	5.8	5.3	3.8	3.8	23.0	25.1	24.1	26.6	25.0
2nd per.	6.2	8.0	9.1	9.6	20.2	46.0	37.0	37.0	34.6
Yr.	12.0	13.3	12.9	13.4	43.2	71.1	61.1	63.6	59.6
'30-'31									
1st per.	10.1	22.8	8.8	5.6	30.0	35.5	30.7	32.8	30.1
2nd per.	13.3	42.2	25.3	25.6	32.9	65.1	44.6	66.0	46.5
Yr.	23.4	65.0	34.1	31.2	62.9	100.6	75.3	98.8	76.6
'31-'32									
1st per.	7.8	72.0	20.5	20.7	79.2	122.3	104.8	120.4	63.2
2nd per.	32.7	73.0	31.2	36.9	38.2	47.8	49.1	75.5	61.0
Yr.	40.5	145.0	51.7	57.6	117.4	170.1	153.9	195.9	124.2
'32-'33									
1st per.	38.2	153.4	96.0	82.7	104.7	194.5	140.5	140.4	85.1
2nd per.	13.1	53.4	35.7	35.8	24.8	25.6	34.3	34.3	38.9
Yr.	51.3	206.8	131.7	118.5	129.5	220.1	174.8	174.7	124.0
'33-'34									
1st per.	23.2	51.1	50.8	52.1	62.3	83.9	71.6	82.3	43.2
2nd per.	8.8	63.3	28.7	30.8	16.7	45.7	39.4	36.1	33.2
Yr.	32.0	114.4	79.5	82.9	79.0	129.7	111.0	118.4	76.4
'29-'34									
1st per.	85.1	304.6	179.9	164.9	299.2	461.3	371.7	402.5	246.6
2nd per.	74.1	239.9	130.0	138.7	132.8	230.2	204.4	248.9	214.2
Replicate A	154.7	556.0	306.7	322.3	430.6	689.2	577.7	661.7	445.5
Replicate B	163.6	533.0	313.2	285.2	433.9	693.9	574.5	641.2	476.0
5 Yrs.	159.2	544.5	309.9	303.6	432.0	691.5	576.1	651.4	460.8

TABLE IV. DRAINAGE LOSSES—WINDSOR SURFACE SOIL LYSIMETERS
SODIUM
(in pounds per acre)

	Enfield v.f.s.l.				Merrimac l. s.			
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal
'29-'30								
1st per.	115.2	22.8	20.5	18.2	278.7	7.0	7.0	7.0
2nd per.	49.7	6.7	4.2	7.4	20.6	6.6	10.0	13.1
Yr.	164.9	29.5	24.7	25.6	299.3	13.6	17.0	20.1
'30-'31								
1st per.	231.6	11.1	7.3	9.4	264.5	13.0	6.6	7.6
2nd per.	49.2	4.4	3.7	4.0	18.6	2.2	2.2	2.3
Yr.	280.8	15.5	11.0	13.4	283.1	15.2	8.8	9.9
'31-'32								
1st per.	178.1	6.6	8.3	7.6	228.3	9.6	10.0	13.2
2nd per.	87.3	16.3	13.4	13.3	39.6	22.3	24.8	22.7
Yr.	265.4	22.9	21.7	20.9	267.9	31.9	34.8	35.9
'32-'33								
1st per.	300.3	10.7	7.9	7.9	295.3	9.9	7.9	9.4
2nd per.	33.4	4.3	4.5	3.5	26.1	5.1	6.1	5.2
Yr.	333.7	15.0	12.4	11.4	321.4	15.0	14.0	14.6
'33-'34								
1st per.	223.6	5.9	5.0	4.6	248.9	10.3	7.0	7.8
2nd per.	74.7	5.7	4.0	3.8	57.7	3.3	3.0	2.8
Yr.	298.3	11.6	9.0	8.4	306.6	13.3	10.0	10.6
'29-'34								
1st per.	1048.8	57.1	49.0	47.7	1315.7	49.8	38.5	45.0
2nd per.	294.4	37.4	29.8	32.0	162.6	39.5	46.1	46.1
Replicate A	1336.7	104.8	73.3	82.0	1456.3	97.2	86.7	88.4
Replicate B	1349.6	84.2	84.3	77.4	1500.3	81.5	82.6	93.8
5 Yrs.	1343.2	94.5	78.8	79.7	1478.3	89.3	84.6	91.1

	Wethersfield l.				Merrimac s. l.				
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	No nitrogen
'29-'30									
1st per.	95.7	26.8	32.9	35.0	226.8	16.6	14.8	6.8	1.5
2nd per.	90.8	13.4	15.9	14.3	30.0	8.1	6.9	10.1	8.5
Yr.	186.5	40.2	48.8	49.3	256.8	24.7	21.7	16.9	10.0
'30-'31									
1st per.	264.1	11.9	11.7	11.2	231.9	19.9	16.1	15.5	6.7
2nd per.	81.0	6.1	6.9	7.8	37.9	3.7	3.8	3.1	3.6
Yr.	345.1	18.0	18.6	19.0	269.8	23.6	19.9	18.6	10.3
'31-'32									
1st per.	187.2	12.1	9.7	11.7	216.9	10.1	11.1	9.3	8.4
2nd per.	104.7	18.9	16.1	14.0	62.7	15.1	15.5	12.7	13.0
Yr.	291.9	31.0	25.8	25.7	279.6	25.2	26.6	22.0	21.4
'32-'33									
1st per.	270.4	11.6	9.5	7.4	284.8	9.5	8.8	7.2	6.5
2nd per.	51.0	5.9	3.3	6.2	33.9	5.8	4.9	4.0	4.9
Yr.	321.4	17.5	12.8	13.6	318.7	15.3	13.7	11.2	11.4
'33-'34									
1st per.	203.5	7.2	6.7	6.8	247.0	6.8	7.2	6.0	5.3
2nd per.	75.1	4.6	3.2	3.2	44.7	3.4	3.3	2.3	3.2
Yr.	278.6	11.8	9.9	10.0	291.7	10.2	10.5	8.3	8.5
'29-'34									
1st per.	1020.9	69.6	70.5	72.1	1207.4	62.9	58.0	44.8	28.4
2nd per.	402.6	48.9	45.4	45.5	209.2	36.1	34.4	32.2	33.2
Replicate A	1405.1	134.2	108.0	125.8	1414.5	101.5	98.8	69.5	64.7
Replicate B	1441.9	102.7	123.9	109.5	1418.8	96.4	85.9	84.5	58.6
5 Yrs.	1423.5	118.5	115.9	117.6	1416.6	99.0	92.4	77.0	61.6

TABLE V. DRAINAGE LOSSES—WINDSOR SURFACE SOIL LYSIMETERS
AMMONIA NITROGEN
(in pounds per acre)

	Enfield v.f.s.l.				Merrimac l. s.			
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal
'29-'30								
1st per.	.35	3.79	.43	.30	.70	39.61	11.95	7.67
2nd per.	2.07	1.38	1.81	.68	1.15	2.05	1.30	.38
Yr.	2.42	5.17	2.24	.98	1.85	41.66	13.25	8.05
'30-'31								
1st per.	.43	1.55	.53	.27	.49	101.58	39.33	.74
2nd per.	.86	1.81	1.10	.40	.90	.93	.49	.47
Yr.	1.29	3.36	1.63	.67	1.39	102.51	39.82	1.21
'31-'32								
1st per.	.40	26.77	3.92	.31	.22	88.42	35.40	5.72
2nd per.	.70	2.08	1.18	.52	.87	.83	.23	.29
Yr.	1.10	28.85	5.10	.83	1.09	89.25	35.63	6.01
'32-'33								
1st per.	1.69	4.27	.60	.60	2.63	24.39	16.80	1.23
2nd per.	.35	.69	.51	1.61	.31	.32	.39	.35
Yr.	2.04	4.96	1.11	2.21	2.94	24.71	17.19	1.58
'33-'34								
1st per.	.30	.94	.65	.15	.21	28.62	4.50	1.01
2nd per.	.99	1.84	.59	.66	.66	.63	.58	.38
Yr.	1.29	2.78	1.24	.81	.87	28.89	5.08	1.39
'29-'34								
1st per.	3.17	37.32	6.13	1.63	4.25	282.26	107.98	16.37
2nd per.	6.97	7.80	5.19	3.87	3.89	4.76	2.99	1.87
Replicate A	9.54	44.25	11.79	8.07	8.66	291.10	110.09	16.40
Replicate B	10.74	47.02	10.85	2.93	7.63	282.94	111.84	20.08
5 Yrs.	10.14	45.14	11.32	5.50	8.14	287.02	110.97	18.24

	Wethersfield l.				Merrimac s. l.				
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	No nitrogen
'29-'30									
1st per.	.12	.32	.44	.37	.74	10.70	1.90	1.17	.39
2nd per.	.58	.84	.26	.74	.57	.49	.30	.99	2.01
Yr.	.70	1.16	.70	1.12	1.31	11.19	2.20	2.16	2.40
'30-'31									
1st per.	.53	2.71	4.09	.58	.93	28.66	12.29	1.01	1.55
2nd per.	.80	2.45	.51	.49	.89	.57	.65	1.44	.29
Yr.	1.33	5.16	4.60	1.07	1.82	29.23	12.94	2.45	1.84
'31-'32									
1st per.	.33	8.89	1.43	.16	.63	41.67	4.23	.38	1.08
2nd per.	.91	.50	.46	.41	1.09	2.79	.93	.35	.48
Yr.	1.24	9.39	1.89	.57	1.72	44.46	5.15	.73	1.56
'32-'33									
1st per.	.74	9.71	.58	.82	.44	8.87	3.82	.48	.31
2nd per.	.61	.31	.17	.17	.16	.13	.15	.25	.15
Yr.	1.35	10.02	.75	.99	.60	9.00	3.97	.73	.46
'33-'34									
1st per.	.16	4.11	.15	.16	.20	27.72	1.04	.50	.15
2nd per.	.38	4.07	.19	.16	.77	5.77	.44	.55	.35
Yr.	.54	8.18	.34	.32	.97	32.48	1.48	1.05	.50
'29-'34									
1st per.	1.88	25.74	6.69	2.09	2.94	117.62	23.27	3.54	3.48
2nd per.	3.28	8.17	1.59	1.97	3.48	9.75	2.47	3.58	3.28
Replicate A	5.49	31.57	5.16	2.98	6.49	128.87	28.66	8.19	7.81
Replicate B	4.83	36.25	11.41	5.14	6.35	125.87	22.82	6.04	5.70
5 Yrs.	5.16	33.91	8.28	4.06	6.42	127.37	25.74	7.12	6.76

TABLE VI. DRAINAGE LOSSES—WINDSOR SURFACE SOIL LYSIMETERS
MANGANESE
(in pounds per acre)

	Enfield v.f.s.l.				Merrimac l. s.			
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal
'29-'30								
1st per.	1.99	12.74	7.41	3.61	2.82	20.74	10.62	5.69
2nd per.	.17	3.52	.94	.83	.54	1.88	.20	.12
Yr.	2.16	16.26	8.35	4.44	3.36	22.62	10.82	5.81
'30-'31								
1st per.	2.23	16.43	9.69	2.15	.86	8.61	3.86	3.98
2nd per.	....	6.42	2.14	.76	....	.60	....	....
Yr.	2.23	22.85	11.83	2.91	.86	9.21	3.86	3.98
'31-'32								
1st per.	....	6.97	4.65	2.55	.63	3.26	1.37	5.21
2nd per.	....	8.11	13.78	9.11	....	4.83	....	6.16
Yr.	....	15.08	18.42	11.66	.63	8.09	1.37	11.37
'32-'33								
1st per.	1.99	15.52	13.65	5.24	2.46	12.84	6.56	4.36
2nd per.	....	....	....	....	....	....	....	....
Yr.	1.99	15.52	13.65	5.24	2.46	12.84	6.56	4.36
'33-'34								
1st per.	.55	2.98	3.71	1.72	....	6.28	3.82	3.05
2nd per.	....	3.54	2.55	.75	....	.65	....	....
Yr.	.55	6.52	6.26	2.47	....	6.93	3.82	3.05
'29-'34								
1st per.	6.76	54.64	39.11	15.27	6.77	51.73	26.23	22.29
2nd per.	.17	21.59	19.41	11.45	.54	7.96	.20	6.28
Replicate A	9.02	74.70	55.94	28.22	7.55	62.13	29.16	28.19
Replicate B	5.83	77.76	61.09	25.22	7.06	57.24	23.70	28.96
5 Yrs.	6.93	76.23	58.52	26.72	7.31	59.69	26.43	28.57

	Wethersfield l.				Merrimac s. l.				
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	No nitrogen
'29-'30									
1st per.	....	....	....	....	.40	21.02	4.83	1.33	....
2nd per.	.06	.35	.11	....	.03	.79	.03	....	.32
Yr.	.06	.35	.11	....	.43	21.81	4.86	1.33	.32
'30-'31									
1st per.	.06	4.72	1.22	.10	.20	25.47	6.22	4.00	.53
2nd per.	....	3.62	....	....	....	1.92	....	....	....
Yr.	.06	8.34	1.22	.10	.20	27.39	6.22	4.00	.53
'31-'32									
1st per.	....	7.62	1.50	....	....	18.22	7.78	....	....
2nd per.	....	22.04	....	....	....	13.43	5.08	....	....
Yr.	....	29.66	1.50	....	....	31.65	12.86	....	....
'32-'33									
1st per.	.58	44.27	5.22	.66	1.33	38.85	23.51	2.56	.28
2nd per.	....	.85	....	....	....	....	....	....	....
Yr.	.58	45.12	5.22	.66	1.33	38.85	23.51	2.56	.28
'33-'34									
1st per.	....	17.13	6.77	....	.58	10.03	12.83	4.55	....
2nd per.	....	10.92	.69	....	....	2.96	1.90	....	....
Yr.	....	28.05	7.36	....	.58	12.99	14.73	4.55	....
'29-'34									
1st per.	.64	73.74	14.61	.76	2.51	113.59	55.17	12.44	.81
2nd per.	.06	37.78	.80	....	.03	19.10	7.01	....	.32
Replicate A	.62	113.15	15.82	.85	2.34	130.35	63.87	15.25	1.44
Replicate B	.77	109.93	14.99	.66	2.75	135.03	60.48	9.62	.81
5 Yrs.	.70	111.52	15.41	.76	2.54	132.69	62.18	12.44	1.13

TABLE VII. DRAINAGE LOSSES—WINDSOR SURFACE SOIL LYSIMETERS
ALUMINUM
(in pounds per acre)

	Enfield v.f.s.l.				Merrimac l. s.			
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal
'29-'30								
1st per.	.71	6.20	3.87	2.36	1.29	20.95	13.27	4.27
2nd per.	.70	8.57	1.65	2.27	....	4.33	.63	.83
Yr.	1.41	14.77	5.52	4.63	1.29	25.28	13.90	5.10
'30-'31								
1st per.	....	42.89	29.23	.37	....	32.06	8.81	....
2nd per.	....	41.17	8.16	....	....	....	....	....
Yr.	....	84.06	37.39	.37	....	32.06	8.81	....
'31-'32								
1st per.	....	53.33	13.99	....	....	25.85	5.04	....
2nd per.	....	47.68	3.17	.66	....	....	....	....
Yr.	....	98.51	17.16	.66	....	25.85	5.04	....
'32-'33								
1st per.	....	38.08	16.07	4.28	Tr.	21.08	1.92	Tr..
2nd per.	....	2.11	....	....	....	.53	.63	....
Yr.	....	40.19	16.07	4.28	Tr.	21.61	2.55	Tr.
'33-'34								
1st per.	Tr.	19.64	12.43	2.52	Tr.	37.19	12.70	.06
2nd per.	....	25.55	4.66	.15	....	.94	....	....
Yr.	Tr.	45.19	17.09	2.67	Tr.	38.13	12.70	.06
'29-'34								
1st per.	.71	160.14	75.59	9.53	1.29	137.13	41.74	4.33
2nd per.	.70	125.08	17.64	3.08	....	5.80	1.26	.83
Replicate A	2.08	289.88	90.68	10.91	1.32	146.54	46.89	4.35
Replicate B	.74	280.56	95.78	14.31	1.25	139.32	39.10	5.97
5 Yrs.	1.41	285.22	93.23	12.61	1.29	142.93	43.00	5.16

	Wethersfield l.				Merrimac s. l.				
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	No nitrogen
'29-'30									
1st per.	....	.81	.87	.45	....	1.05	1.08	1.07	....
2nd per.	.73	.64	.70	....	1.38	1.55	1.68	.69	.75
Yr.	.73	1.45	1.57	.45	1.38	2.60	2.76	1.76	.75
'30-'31									
1st per.	....	....	....	....	....	3.70	1.60	....	....
2nd per.	....	....	....	....	....	....	....	....	....
Yr.	....	....	....	....	....	3.70	1.60	....	....
'31-'32									
1st per.	....	....	....	....	....	1.51	....	....	....
2nd per.	....	....	....	....	....	....	....	....	....
Yr.	....	....	....	....	....	1.51	....	....	....
'32-'33									
1st per.	Tr.	15.92	Tr.	Tr.	....	23.83	4.02	Tr.	Tr.
2nd per.	....	.34	....	....	....	....	....	....	....
Yr.	Tr.	16.26	Tr.	Tr.	....	23.83	4.02	Tr.	Tr.
'33-'34									
1st per.	Tr.	21.22	.56	Tr.	Tr.	26.36	7.61	.03	Tr.
2nd per.	.16	15.48	.16	....	.08	6.90	.29	.11	.07
Yr.	.16	36.70	.72	Tr.	.08	33.26	7.90	.14	.07
'29-'34									
1st per.	Tr.	37.95	1.43	.45	Tr.	56.45	14.31	1.10	Tr.
2nd per.	.89	16.46	.86	....	1.46	8.45	1.97	.80	.82
Replicate A	1.61	56.11	1.64	.90	2.84	69.00	18.22	1.25	.15
Replicate B	.17	52.70	2.94	....	.08	60.80	14.33	2.55	1.49
5 Yrs.	.89	54.41	2.29	.45	1.46	64.90	16.28	1.90	.82

Table VIII. Drainage Losses—Windsor Surface Soil Lysimeters
NITRATE NITROGEN
(in pounds per acre)

	Enfield v.f.s.l.				Merrimac l. s.			
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal
'29-'30								
1st per.	192.5	146.6	142.7	108.0	208.2	118.0	148.6	128.0
2nd per.	14.1	24.8	16.3	20.6	6.7	6.0	6.0	6.6
Yr.	206.6	171.4	159.0	128.6	214.9	124.0	154.6	134.6
'30-'31								
1st per.	210.7	164.3	153.3	93.6	218.6	72.9	90.5	80.3
2nd per.	13.5	43.6	37.9	29.3	5.2	4.1	5.3	6.7
Yr.	224.2	207.9	191.2	122.9	223.8	77.0	95.8	87.0
'31-'32								
1st per.	173.1	86.5	104.4	75.7	192.7	65.7	106.2	82.1
2nd per.	30.3	67.2	70.6	81.1	11.4	13.8	11.9	35.3
Yr.	203.4	153.7	175.0	156.8	204.1	79.5	118.1	117.4
'32-'33								
1st per.	212.0	165.4	177.8	116.1	203.3	126.7	173.2	92.2
2nd per.	5.4	3.8	4.3	5.6	3.3	2.6	4.2	5.3
Yr.	217.4	169.2	182.1	121.7	206.6	129.3	177.4	97.5
'33-'34								
1st per.	187.2	52.3	76.9	58.7	210.5	74.6	142.9	91.0
2nd per.	17.6	66.2	71.6	33.2	9.2	8.5	4.5	5.5
Yr.	204.8	118.5	148.5	91.9	219.7	83.1	147.4	96.5
'29-'34								
1st per.	975.5	615.1	655.1	452.1	1033.3	457.9	661.4	473.6
2nd per.	80.9	205.6	200.7	169.8	35.8	35.0	31.9	59.4
Replicate A	1067.4	819.6	854.3	634.8	1067.6	485.3	720.7	536.0
Replicate B	1045.4	821.8	855.8	609.0	1070.6	500.5	665.8	530.1
5 Yrs.	1056.4	820.7	855.8	621.9	1069.1	492.9	693.3	533.0

	Wethersfield l.				Merrimac s. l.				
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	No nitrogen
'29-'30									
1st per.	167.2	158.4	160.5	99.7	250.3	201.2	219.7	174.6	76.4
2nd per.	55.9	31.6	50.6	35.4	12.1	11.4	10.4	12.4	11.7
Yr.	223.1	190.0	208.1	135.1	263.4	212.6	230.1	187.0	88.1
'30-'31									
1st per.	220.4	153.3	189.6	91.7	233.9	172.4	169.2	119.1	58.8
2nd per.	23.3	52.4	28.3	22.7	12.6	9.2	9.6	15.7	15.6
Yr.	243.7	205.7	217.9	114.4	246.5	181.6	178.8	134.8	74.4
'31-'32									
1st per.	169.5	98.2	124.4	92.7	201.9	100.9	118.7	102.8	34.6
2nd per.	42.3	79.3	48.0	53.2	24.5	28.5	24.4	48.3	26.7
Yr.	211.8	177.5	172.4	145.9	226.4	129.4	143.1	151.1	61.3
'32-'33									
1st per.	202.2	169.1	181.3	113.8	215.7	172.4	181.0	114.2	39.1
2nd per.	5.5	8.7	6.3	7.1	3.4	1.5	6.0	8.0	7.1
Yr.	207.7	177.8	187.6	120.9	219.1	173.9	187.0	122.2	46.2
'33-'34									
1st per.	188.1	67.6	162.9	138.1	201.1	83.5	152.5	118.7	21.8
2nd per.	28.0	64.4	28.7	11.7	8.6	31.5	11.8	8.8	6.3
Yr.	216.1	132.0	191.6	149.8	209.7	115.0	164.3	127.5	28.1
'29-'34									
1st per.	947.4	646.6	818.7	536.0	1102.9	730.4	841.1	629.4	230.7
2nd per.	155.0	236.4	161.9	130.1	61.2	82.1	62.2	93.2	67.4
Replicate A	1108.1	886.7	996.9	731.3	1145.4	833.6	899.0	725.4	295.2
Replicate B	1096.7	879.3	964.3	600.9	1182.8	791.4	907.6	719.8	301.1
5 Yrs.	1102.4	883.0	980.6	666.1	1164.1	812.5	903.3	722.6	298.1

TABLE IX. DRAINAGE LOSSES—WINDSOR SURFACE SOIL LYSIMETERS
SULFUR AS SULFATE
(in pounds per acre)

	Enfield v.f.s.l.				Merrimac l. s.			
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal
'29-'30								
1st per.	32.0	29.6	11.1	11.9	34.1	147.4	11.6	14.6
2nd per.	50.7	62.1	21.2	27.8	11.5	34.1	16.0	12.2
Yr.	82.7	91.7	32.3	39.7	45.6	181.5	27.6	26.8
'30-'31								
1st per.	37.1	74.5	11.7	15.1	48.8	247.9	34.3	24.4
2nd per.	57.9	142.1	37.2	43.9	21.7	37.4	26.1	26.6
Yr.	95.0	216.6	48.9	59.0	70.5	285.3	60.4	51.0
'31-'32								
1st per.	27.2	141.9	19.1	24.4	45.3	223.1	39.1	26.3
2nd per.	67.3	136.6	55.7	46.6	23.0	42.5	29.4	27.7
Yr.	94.5	278.5	74.8	71.0	68.3	265.6	68.5	54.0
'32-'33								
1st per.	74.1	219.8	52.9	57.2	49.7	242.8	38.5	48.1
2nd per.	42.4	92.6	54.8	49.1	15.0	30.0	17.4	17.0
Yr.	116.5	312.4	107.7	106.3	64.7	272.8	55.9	65.1
'33-'34								
1st per.	11.9	36.9	3.5	20.3	21.5	175.4	17.9	16.8
2nd per.	55.7	170.4	32.3	35.3	36.1	58.4	26.4	27.2
Yr.	67.6	207.3	35.8	55.6	57.6	233.8	44.3	44.0
'29-'34								
1st per.	182.3	502.7	98.3	128.9	199.4	1036.6	141.4	130.2
2nd per.	274.0	603.8	221.2	202.7	107.3	202.4	115.3	110.7
Replicate A	441.9	1079.5	314.3	341.1	310.2	1258.8	261.1	227.0
Replicate B	470.6	1133.5	284.8	322.1	303.2	1219.2	252.3	234.8
5 Yrs.	456.3	1106.5	299.5	331.6	306.7	1239.0	256.7	230.9

	Wethersfield l.				Merrimac s. l.				
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal.	No nitrogen
'29-'30									
1st per.	15.4	98.5	13.1	15.2	50.9	188.4	38.4	39.7	43.0
2nd per.	25.4	64.9	18.9	21.0	11.0	31.1	14.4	14.0	11.3
Yr.	40.8	163.4	32.0	36.2	61.9	219.5	52.8	53.7	54.3
'30-'31									
1st per.	52.6	138.5	21.4	25.8	59.4	224.0	41.1	39.9	50.3
2ndper.	45.1	115.3	42.0	43.7	21.2	58.4	32.8	33.4	25.1
Yr.	97.7	253.8	63.4	69.5	80.6	282.4	73.9	73.3	75.4
'31-'32									
1st per.	34.3	152.2	18.3	23.8	47.3	191.5	26.8	25.2	32.3
2nd per.	39.0	96.7	44.9	37.8	21.1	50.3	26.0	21.6	24.6
Yr.	73.3	248.9	63.2	61.6	68.4	241.8	52.8	46.8	56.9
'32-'33									
1st per.	48.5	202.8	45.1	54.8	57.5	239.9	49.7	46.1	56.9
2nd per.	19.9	81.7	35.4	20.4	18.2	43.5	18.0	18.8	15.6
Yr.	68.4	284.5	80.5	75.2	75.7	283.4	67.7	64.9	72.5
'33-'34									
1st per.	20.6	74.7	7.8	11.4	39.6	142.2	10.0	23.6	35.6
2nd per.	30.3	132.5	23.5	27.5	21.8	86.9	33.3	23.5	23.1
Yr.	50.9	207.2	31.3	38.9	61.4	229.1	43.3	47.1	58.7
'29-'34									
1st per.	171.4	666.7	105.7	131.0	254.7	986.0	166.0	174.5	218.1
2nd per.	159.7	491.1	164.7	150.3	93.3	270.2	124.5	111.3	99.7
Replicate A	326.0	1164.9	264.4	278.5	349.1	1260.7	292.8	283.7	310.0
Replicate B	337.4	1150.6	276.4	284.1	346.9	1251.7	288.3	287.9	325.5
5 Yrs.	331.1	1157.8	270.4	281.3	348.0	1256.2	290.5	285.8	317.8

TABLE X. DRAINAGE LOSSES—WINDSOR SURFACE SOIL LYSIMETERS
BICARBONATES
(in pounds per acre)

	Enfield v.f.s.l.				Merrimac l. s.			
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal
'29-'30								
1st per.	14.9	1.9	2.9	5.2	30.6	....	....	8.9
2nd per.	45.8	7.6	18.9	22.6	40.2	7.1	17.2	24.5
Yr.	60.7	9.5	21.8	27.8	70.8	7.1	17.2	33.4
'30-'31								
1st per.	21.1	....	....	5.2	24.7	....	....	15.8
2nd per.	51.4	....	3.5	14.8	50.5	17.5	26.2	34.9
Yr.	72.5	....	3.5	20.0	75.2	17.5	26.2	50.7
'31-'32								
1st per.	26.3	4.4	6.3	19.7	47.2	6.1	10.4	38.7
2nd per.	65.7	....	3.5	3.8	59.2	8.9	23.3	24.0
Yr.	92.0	4.4	9.8	23.5	106.4	15.0	33.7	62.7
'32-'33								
1st per.	58.4	....	2.4	7.1	98.3	....	10.6	56.6
2nd per.	73.3	....	27.6	17.4	80.7	17.9	34.7	46.4
Yr.	131.7	....	30.0	24.5	179.0	17.9	45.3	103.0
'33-'34								
1st per.	15.3	....	....	1.1	27.7	....	....	4.2
2nd per.	62.2	....	....	14.6	72.8	....	23.3	34.9
Yr.	77.5	....	....	15.7	100.5	....	23.3	39.1
'29-'34								
1st per.	136.0	6.3	11.6	38.3	228.5	6.1	21.0	124.2
2nd per.	298.4	7.6	53.5	73.2	303.4	51.4	124.7	164.7
Replicate A	431.6	11.9	62.4	96.8	577.4	55.1	151.9	283.2
Replicate B	437.2	15.9	67.9	126.3	486.4	59.9	139.5	294.6
5 Yrs.	434.4	13.9	65.1	111.5	531.9	57.5	145.7	288.9

	Wethersfield l.				Merrimac s. l.				
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	No nitrogen
'29-'30									
1st per.	20.7	20.9	20.0	23.1	28.4	11.7	11.9	21.0	27.6
2nd per.	21.9	22.5	44.2	34.1	41.3	26.2	26.8	55.2	55.9
Yr.	42.6	43.4	64.2	57.2	69.7	37.9	38.7	76.2	83.5
'30-'31									
1st per.	30.0	10.1	12.6	28.7	26.7	.9	4.5	25.0	39.0
2nd per.	60.3	28.5	26.8	34.1	87.0	28.1	45.6	73.7	40.9
Yr.	90.3	38.6	39.4	62.8	113.7	29.0	50.1	98.7	79.9
'31-'32									
1st per.	46.7	17.7	27.5	37.9	47.7	10.6	29.6	59.1	44.7
2nd per.	70.7	11.4	25.6	34.3	122.5	22.4	47.6	72.6	80.1
Yr.	117.4	29.1	53.1	72.2	170.2	33.0	77.2	131.7	124.8
'32-'33									
1st per.	88.9	2.8	16.6	44.9	48.6	....	10.6	29.8	40.7
2nd per.	76.7	14.5	25.0	32.1	112.7	23.1	42.0	41.0	55.2
Yr.	165.6	17.3	41.6	77.0	161.3	23.1	52.6	70.8	95.9
'33-'34									
1st per.	22.1	....	....	13.4	14.6	....	....	5.4	15.3
2nd per.	56.8	....	14.4	26.7	58.4	....	4.9	34.0	57.8
Yr.	78.9	....	14.4	40.1	73.0	....	4.9	39.4	73.1
'29-'34									
1st per.	208.4	51.5	76.7	148.0	166.0	23.2	56.6	140.3	167.3
2nd per.	286.3	76.9	136.0	161.3	421.9	99.8	166.9	276.5	289.9
Replicate A	520.4	157.6	201.7	331.1	551.1	102.8	247.3	418.0	525.0
Replicate B	469.0	99.3	223.6	287.4	624.7	143.2	199.6	415.6	388.9
5 Yrs.	494.7	128.4	212.7	309.3	587.9	123.0	223.5	416.8	457.2

Table XI. Drainage Losses—Windsor Surface Soil Lysimeters
CHLORINE
(in pounds per acre)

	Enfield v.f.s.l.				Merrimac l. s.			
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal
'29-'30								
1st per.*	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
2nd per.*	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Yr.	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
'30-'31								
1st per.	4.6	3.0	2.1	3.4	4.6	1.5	4.0	2.5
2nd per.*	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Yr.	10.6	9.0	8.1	9.4	10.6	7.5	10.0	8.5
'31-'32								
1st per.	14.4	12.4	8.0	9.2	15.6	9.9	10.7	6.5
2nd per.	8.6	10.4	12.1	13.0	8.9	6.9	7.1	13.3
Yr.	23.0	22.8	20.1	22.2	24.5	16.8	17.8	19.8
'32-'33								
1st per.	22.6	15.2	15.1	10.4	15.8	13.2	10.4	8.4
2nd per.	5.6	5.5	5.8	5.8	6.0	6.3	6.0	6.0
Yr.	28.2	20.7	20.9	16.2	21.8	19.5	16.4	14.4
'33-'34								
1st per.	12.3	7.1	6.5	5.6	12.2	12.3	7.6	7.9
2nd per.	5.0	1.9	6.8	5.2	4.6	4.4	3.6	4.8
Yr.	17.3	9.0	13.3	10.8	16.8	16.7	11.2	12.7
'29-'34								
1st per.	61.9	45.7	39.7	36.6	56.2	44.9	40.7	33.3
2nd per.	31.2	29.8	36.7	36.0	31.5	29.6	28.7	36.1
Replicate A	95.4	74.1	79.9	73.5	91.7	81.0	70.5	74.0
Replicate B	90.9	76.9	72.9	71.6	83.8	68.1	68.2	64.8
5 Yrs.	93.1	75.5	76.4	72.6	87.7	74.5	69.4	69.4

	Wethersfield l.				Merrimac s. l.				
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	No nitrogen
'29-'30									
1st per.*	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
2nd per.*	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Yr.	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
'30-'31									
1st per.	5.4	3.8	2.7	5.0	5.7	2.9	4.4	4.0	5.0
2nd per.*	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Yr.	11.4	9.8	8.7	11.0	11.7	8.9	10.4	10.0	11.0
'31-'32									
1st per.	11.0	8.0	7.2	6.8	17.9	9.1	8.6	5.5	7.6
2nd per.	4.5	12.7	3.5	6.1	5.1	3.4	4.3	3.6	4.9
Yr.	15.5	20.7	10.7	12.9	23.0	12.5	12.9	9.1	12.5
'32-'33									
1st per.	13.9	12.7	11.8	7.2	10.6	14.1	11.8	4.8	6.7
2nd per.	7.0	6.8	6.0	13.6	6.0	6.0	6.0	6.0	6.0
Yr.	20.9	19.5	17.8	20.8	16.6	20.1	17.8	10.8	12.7
'33-'34									
1st per.	10.7	7.1	6.1	6.9	11.8	8.3	7.4	7.3	7.1
2nd per.	4.8	4.7	5.5	3.3	2.7	3.5	3.8	2.6	3.0
Yr.	15.5	11.8	11.6	10.2	14.5	11.8	11.2	9.9	10.1
'29-'34									
1st per.	49.0	39.6	35.8	33.9	54.0	42.4	40.2	29.6	34.4
2nd per.	28.3	36.2	27.0	35.0	25.8	24.9	26.1	24.2	25.9
Replicate A	78.1	77.4	63.5	68.0	75.3	66.5	68.4	53.7	58.8
Replicate B	76.5	74.2	62.2	69.8	84.2	68.2	64.1	53.9	61.9
5 Yrs.	77.3	75.8	62.8	68.9	79.8	67.3	66.3	53.8	60.3

*Approximate estimate.

TABLE XII. DRAINAGE LOSSES—WINDSOR SURFACE SOIL LYSIMETERS
PHOSPHORUS
(in pounds per acre)

	Enfield v.f.s.l.				Merrimac l. s.			
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal
'29-'30								
1st per.*	.02	.02	.02	.02	.02	.02	.02	.02
2nd per.*	.15	.15	.15	.15	.15	.15	.15	.15
Yr.	.17	.17	.17	.17	.17	.17	.17	.17
'30-'31								
1st per.*	.04	.04	.04	.04	.04	.04	.04	.04
2nd per.*	.10	.10	.10	.10	.10	.10	.10	.10
Yr.	.14	.14	.14	.14	.14	.14	.14	.14
'31-'32								
1st per. *	.04	.04	.04	.04	.04	.04	.04	.04
2nd per.*	.10	.10	.10	.10	.10	.10	.10	.10
Yr.	.14	.14	.14	.14	.14	.14	.14	.14
'32-'33								
1st per.	.21	.07	.04	.02	.04	.03	.03	.05
2nd per.	.18	.15	.15	.15	.30	.15	.15	.15
Yr.	.39	.22	.19	.17	.34	.18	.18	.20
'33-'34								
1st per.	.04	.04	.03	.07	.13	.05	.06	.07
2nd per.	.08	.08	.03	.03	.30	.13	.08	.09
Yr.	.12	.12	.06	.10	.43	.18	.14	.16
'29-'34								
1st per.	.35	.21	.17	.19	.27	.18	.19	.22
2nd per.	.61	.58	.53	.53	.95	.63	.58	.59
Replicate A	.93	.84	.72	.69	1.27	.80	.78	.76
Replicate B	.98	.73	.68	.74	1.17	.82	.77	.85
5 Yrs.	.96	.79	.70	.72	1.22	.81	.77	.81

	Wethersfield l.				Merrimac s. l.				
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	No nitrogen
'29-'30									
1st per.	.08	.03	.05	.02	.08	.13	.29	.13	.08
2nd per.	.15*	.15*	.15*	.15*	1.29	.63	1.12	.77	.98
Yr.	.23	.18	.20	.17	1.37	.76	1.41	.90	1.06
'30-'31									
1st per.	.04*	.04*	,04*	.04*	.75	.20	.40	.50	.60
2nd per.	.10*	.10*	.10*	.10*	1.25	.40	.60	.80	1.00
Yr.	.14	.14	.14	.14	2.00	.60	1.00	1.30	1.60
'31-'32									
1st per.	.04*	.04*	.04*	.04*	1.00	.10	.50	.75	.90
2nd per.	.10*	.10*	.10*	.10*	2.06	.13	1.12	1.57	1.62
Yr.	.14	.14	.14	.14	3.06	.23	1.62	2.32	2.52
'32-'33									
1st per.	.04	.04	.04	.03	4.29	.54	.44	1.93	1.85
2nd per.	.45	.15	.15	.15	10.05	.26	1.93	1.82	5.12
Yr.	.49	.19	.19	.18	14.34	.80	2.37	3.75	6.97
'33-'34									
1st per.	.09	.04	.06	.05	.68	.19	.43	.68	.47
2nd per.	.17	.06	.06	.03	1.89	.15	.35	.21	1.51
Yr.	.26	.10	.12	.08	2.57	.34	.78	.89	1.98
'29-'34									
1st per.	.29	.19	.23	.18	6.80	1.16	2.06	3.99	3.90
2nd per.	.97	.56	.56	.53	16.54	1.57	5.12	5.17	10.23
Replicate A	1.49	.75	.84	.71	21.15	3.15	6.75	9.48	13.07
Replicate B	1.04	.75	.73	.72	25.53	2.30	7.60	8.85	15.19
5 Yrs.	1.26	.75	.79	.71	23.34	2.73	7.18	9.16	14.13

*Approximate estimate.

TABLE XIII. pH OF DRAINAGE WATER BY PERIODS
WINDSOR SURFACE SOIL LYSIMETERS

Period	Enfield v.f.s.l.				Merrimac loamy sand			
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal
'29-'30								
1st per.	7.40	4.70	5.20	6.60	7.30	4.35	4.60	6.30
2nd per.	7.80	4.55	7.30	7.50	7.55	5.10	7.45	7.60
'30-'31								
1st per.	7.20	4.40	4.50	6.60	6.90	4.70	5.00	6.65
2nd per.	7.45	4.30	4.70	7.10	7.60	6.85	7.15	6.70
'31-'32								
1st per.	6.90	4.10	4.35	6.90	7.30	4.40	5.60	6.90
2nd per.	6.80	4.40	4.75	5.30	7.00	6.85	6.95	7.05
'32-'33								
1st per.	6.90	4.15	4.30	5.30	6.55	4.40	5.20	7.50
2nd per.	7.05	4.50	6.80	6.85	6.80	6.90	6.95	6.65
'33-'34								
1st per.	7.10	4.15	4.35	5.00	7.10	4.15	4.45	6.40
2nd per.	6.95	4.25	4.60	6.20	6.95	4.70	6.65	6.55

Period	Wethersfield loam				Merrimac sandy loam				
	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	Sodium nitrate	Ammonium sulfate	Urea	Cottonseed meal	No nitrogen
'29-'30									
1st per.	7.80	7.45	7.60	7.70	7.40	6.95	7.20	7.25	7.50
2nd per.	7.70	7.70	7.20	7.60	7.10	7.45	7.40	6.95	6.90
'30-'31									
1st per.	7.15	6.30	6.95	6.45	7.20	5.90	6.35	7.10	7.05
2nd per.	6.85	6.85	6.50	6.50	6.85	6.80	6.30	6.95	7.25
'31-'32									
1st per.	7.20	5.70	7.00	7.40	6.70	4.75	6.15	7.05	6.75
2nd per.	6.75	6.55	6.75	6.55	6.80	6.30	6.70	6.45	6.45
'32-'33									
1st per.	6.35	4.70	7.40	7.00	6.80	4.30	5.10	7.40	6.90
2nd per.	6.55	6.30	6.30	6.05	6.40	6.50	6.00	5.80	6.50
'33-'34									
1st per.	7.30	4.35	5.60	7.15	7.00	4.25	4.65	6.30	7.10
2nd per.	6.90	4.35	5.95	6.20	6.50	4.45	5.95	6.10	5.95

TABLE XIV. TOTAL NITROGEN CONTENT OF WINDSOR LYSIMETER SOILS AT END OF FIVE YEARS IN THE SURFACE SOIL TANKS IN COMPARISON WITH ORIGINAL SOILS

		Nitrogen Per cent	Nitrogen Pounds per acre	Gain or loss over original soil Lbs. N. per A.
Enfield v.f.s.l.				
Sodium nitrate	1	.1122	1800.0	92.7—
	2	.1123	1801.3	91.4—
	Av.	.11225	1800.65	92.05—
Ammonium sulfate	3	.1127	1807.7	85.0—
	4	.1130	1812.5	80.2—
	Av.	.11285	1810.1	82.6—
Urea	5	.1134	1818.9	73.8—
	6	.1130	1812.5	80.2—
	Av.	.1132	1815.7	77.0—
Cottonseed meal	7	.1200	1924.8	32.1+
	8	.1233	1977.7	52.9+
	Av.	.12165	1951.25	42.5+
Original Soil		.1180	1892.7	
Merrimac loamy sand				
Sodium nitrate	9	.0500	978.0	101.7+
	10	.0500	978.0	101.7+
	Av.	.0500	978.0	101.7+
Ammonium sulfate	11	.0537	1050.4	174.1+
	12	.0546	1068.0	191.7+
	Av.	.05415	1059.2	182.9+
Urea	13	.0475	929.1	52.8+
	14	.0486	950.6	74.3+
	Av.	.04805	939.85	63.55+
Cottonseed meal	15	.0604	1181.4	305.1+
	16	.0560	1095.4	219.1+
	Av.	.05820	1138.4	262.1+
Original Soil		.0448	876.3	

TABLE XIV.—Continued)

		Nitrogen Per cent	Nitrogen Pounds per acre	Gain or loss over original soil Lbs. N. per A.
Wethersfield loam				
Sodium nitrate	17	.1110	1753.8	41.1—
	18	.1090	1722.2	72.7—
	Av.	.1100	1738.0	56.9—
Ammonium sulfate	19	.1147	1812.3	17.4+
	20	.1143	1805.9	11.0+
	Av.	.1145	1809.1	14.2+
Urea	21	.1130	1785.4	9.5—
	22	.1120	1769.6	25.3—
	Av.	.1125	1777.5	17.4—
Cottonseed meal	23	.1253	1979.7	184.8+
	24	.1248	1971 8	176.9+
	Av.	.12505	1975.75	180.85+
Original Soil		.1136	1794.9	
Merrimac sandy loam				
Sodium nitrate	25	.0732	1486.0	4 1+
	26	.0680	1380.4	101.5—
	Av.	.07060	1433.2	48 7—
Ammonium sulfate	27	.0775	1573.2	91.3+
	28	.0770	1563.1	81.2+
	Av.	.07725	1568.15	86.25+
Urea	29	.0745	1512.4	30.5+
	30	.0765	1553.0	71.1+
	Av.	.0755	1532.7	50.8+
Cottonseed meal	31	.0785	1593.6	111.7+
	32	.0780	1583.4	101.5+
	Av.	.07825	1588.5	106.6+
No nitrogen	33	.0720	1461.6	20.3—
	34	.0690	1400.7	81.2—
	Av.	.0705	1431.15	50.75—
Original Soil		.0730	1481.9	